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**General Technical
Report RM-204**

# Insects of Windbreaks and Related Plantings:

## Distribution, Importance, and Management

## Conference Proceedings

December 6, 1988
Louisville, Kentucky

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Abstract

This proceedings is a compilation of 9 articles on insects associated with windbreaks, presented at a special conference during the Entomological Society of America 1988 National Conference. The uniqueness of the windbreak ecosystem, the importance and management of insect pests in windbreaks, the effect of windbreaks on survival of crop pests, and potential windbreak pest problems are discussed.

# Preface

In 1986, an International Symposium on Windbreak Technology was held in Lincoln Nebraska. This symposium documented for the first time the world wide importance of windbreaks and summarized the available technical information concerning windbreak use, establishment, and maintenance.

We realized after this conference that there was an abundance of information on insect pests of windbreaks as well as other insects that utilize windbreaks. However, this information was scattered and could only briefly be summarized in the proceedings of the symposium. Also, most professional entomologists are unaware of the widespread use and importance of windbreaks, the effects of insects on windbreak function, and effects of windbreaks on the survival of crop insect pests.

This conference and its proceedings of the papers in the conference will attempt to address both of these needs: the need to summarize more completely available information and to inform other entomologists. The speakers chosen for the informal conference have extensive experience in windbreak entomology or in windbreak forestry. They will address the uniqueness of windbreaks compared to other forest systems, the importance and management of tree insect pests in windbreaks, and the effects of windbreaks on the survival and distribution of crop pests.

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# Insects of Windbreaks and Related Plantings: Distribution, Importance, and Management

## Conference Proceedings

December 6, 1988
Louisville, Kentucky

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# Contents

# Windbreaks Are Bulwarks of the Prairie[1]

Melvin J. Baughman[2]

Abstract.--Windbreaks are used to protect agricultural fields, livestock, farmsteads, highways and recreation sites. Field windbreaks are designed quite differently from farmstead windbreaks. Windbreaks resemble woodland plantations, but take on characteristics of natural woodlands over time. Because of the importance of each tree, only low levels of pest damage are tolerable.

## INTRODUCTION

A century ago Clarence Wedge of Minnesota said, "We need protection from blizzards almost as much as we do from burglars. Great belts should be planted on the prairie districts...forming a network of barriers to our storms" (Scholten 1988). Thousands of miles of windbreaks were planted during the 1920's and 30's. Many have since been removed because they became decadent, took up too much valuable cropland or interferred with new irrigation systems. Windbreaks, though, provide the same benefits now as in the Dust Bowl days and more efficient designs are available.

Windbreaks have great value when properly designed, planted and maintained. In my opinion the terms windbreak and shelterbelt are synonyms. As used here, the term windbreak refers to any long, narrow band of trees planted to reduce wind velocity. Windbreaks are often planted to protect agricultural fields, livestock pens, farmsteads, homes, highways, and recreation sites.

## WINDBREAK BENEFITS

Field windbreaks produce different benefits depending on their design and location. Windbreaks can reduce soil erosion. Soil particles start to move when wind forces overcome gravity. The minimum windspeed required to start movement depends on the size and weight of soil particles. Where a mixture of single-grained materials is present, the practical windspeed which initiates movement under field conditions is about 13 miles per hour, measured at one foot above the ground surface. Wind-blown soil can cause physical damage to young agricultural plants. Loss of smaller-sized soil particles and organic matter can increase soil erodibility, reduce the water-holding capacity of the cultivated layer, and deplete fertility. In addition, blowing soil can reduce visibility on highways and fill roadside ditches (Swan, Halsey and Breyer 1979).

Windbreaks increase yields of certain agricultural crops. There is a comparatively low response from drought-hardy small grains and maize grown under dry farming conditions in sub-humid to semi-arid climates. Moderately responsive crops include rice and fodder crops like alfalfa, lupine, clover grass and seed of wheat grasses. The most responsive crops are garden crops, including lentils, potatoes, tomatoes, cucumbers, beets, strawberries, water melons; and such crops as tobacco, tea, citrus, flower bulbs, apples and pears (Stoeckeler 1965).

There have been a few financial analyses of windbreak effects on crop yields. A 1936 study found that windbreaks around California citrus groves increased revenue by $92 per acre per year. The comparable value would be much higher today because of inflation (Stoeckeler 1965). In Nebraska winter wheat on a 160 acre field protected by multi-row windbreaks was estimated to yield a net present value of $22,184, assuming a 5 percent real discount rate, and produced an internal rate of return over 15 percent (Brandle, Johnson and Dearmont 1984). On the other hand, a North Dakota study concluded that in a 160 acre wheat field with four single-row windbreaks, wheat production would be 3 bushels per acre less than in an unprotected field of the same size. When the cost of establishing and maintaining the windbreaks was added to the crop value loss, the fields protected by windbreaks produced a revenue loss (McMartin, Frank and Heintz 1974). Financial benefits from windbreaks appear to vary depending on the crop, windbreak design and geographic area.

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[1]Paper presented at the conference "Insects of windbreaks and related plantings: distribution, importance and management." Entomological Society of America 1988 National Conference, Louisville, KY, December 6, 1988.

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Crop yields are affected by microclimatic influences of windbreaks. In the Northern Plains especially, windbreaks increase snow accumulation on adjacent fields thus increasing soil moisture. This is one of the most important benefits from windbreaks. Because of the shadow cast by a windbreak, solar radiation has been measured at 95 percent of open field conditions at a distance of approximately 2H--where H refers to the average height of the tallest trees. Under windy conditions soil and air temperatures are generally higher in sheltered sites during daytime and lower at night. Although the mean temperature might not be significantly different in the field of influence of a windbreak compared to the open, the change in diurnal variation can affect plant growth considerably. On the leeward side of windbreaks, air humidity is reported to be higher and dewfall may be increased up to 300 percent. Windbreaks also reduce evaporation (Darnhofer 1982).

Windbreaks offer habitat for certain wildlife species, particularly birds and small mammals. Depending on the tree and shrub species used, windbreaks can provide cover, food and nesting sites. During severe winter storms, windbreaks offer critically important cover.

Farmstead windbreaks offer somewhat different benefits than field windbreaks. They create a more pleasant living environment by reducing wind velocity. In winter, abatement of cold winds reduces the windchill effect on people and livestock. Wind protection reduces the amount of livestock feed needed in winter and reduces livestock deaths from severe winter storms. Winter heating bills can be reduced up to 30 percent mainly as a result of reduced air exchange when windbreaks protect homes or other farm buildings. By controlling snow drifting, windbreaks create a more productive human environment and reduce the time and cost of snow removal. In summer trees moderate the hot, searing winds and raise the humidity, producing an air conditioning effect that cools the air. Farmstead windbreaks also filter dust from the air that could enter buildings and equipment. Finally, they add much beauty to the farmstead and rural landscape (Scholten 1988).

In recent years living snow fences have become popular in windswept areas to control snow drifting over highways. By controlling snow drifts they reduce traffic hazards, decrease snow removal costs and in addition offer wildlife habitat, winter livestock protection and environmental beautification (Interagency Living Snow Fence Program 1985).

## WINDBREAKS COMPARED TO WOODLANDS

Windbreaks more closely resemble tree plantations than natural woodlands. Windbreaks are even-aged since all trees are planted at the same time. Tree species are selected for such traits as crown density, branch retention, leaf retention (conifers) and pest resistance. Spacing between trees is regulated. Site preparation before planting, weed control and even irrigation are carefully applied.

Natural woodlands on the other hand may have trees of many ages and species. Desirable species and individuals are favored by removing undesirable trees. Species are usually favored because of straight stems, moderate sized crowns, self-pruning, wood characteristics, and pest resistance. Trees are randomly spaced. There is little opportunity to prepare sites for regeneration. Weed control is usually impractical. Irrigation is not practical or economical.

Over long periods of time, however, windbreaks may take on some of the characteristics of natural woodlands. Natural regeneration of trees and shrubs may occur in old windbreaks. Species not originally planted will invade the windbreak. Planted trees will die from pest or environmental problems and their growing space will be occupied by nearby trees that expand their crowns or by new invaders. The initial spacing will be lost. Windbreak density will either increase or decrease depending on ecological developments. Along with a change in species and spacing may come a slight change in wildlife and aesthetic value of the windbreak. Renovation of an old windbreak may be needed if desired benefits decline over time.

## FIELD WINDBREAK DESIGN

The adage that "form follows function" certainly fits windbreaks. Field windbreaks are designed differently from farmstead windbreaks. Recommended windbreak design has changed over time as new research information became available. Field windbreaks planted during the Dust Bowl days commonly had 5 to 10 rows. Today it is most common to plant 1-row field windbreaks, especially where snow distribution is important (Hintz 1985).

The area protected by a field windbreak depends on wind speed and windbreak height and density. Really useful shelter rarely extends beyond 15 or 20 heights on the leeward side of a windbreak (Caborn 1960) although wind reduction may be discernible to 40 H (Darnhofer 1982). In addition, wind velocity may be reduced as far as 10 H in front of a windbreak giving useful shelter for 2 to 5 H on the windward side depending on windbreak density (Caborn 1960).

Windbreaks are most effective when oriented perpendicular to prevailing winds which occur at times when windbreak effects are desired. Most windbreaks are oriented east-west or north-south with the greatest area of protection to the south and east respectively. Although a southwest-northeast orientation would be most effective in some geographic areas, our

rectangular survey system has resulted in field boundaries oriented north-south and east-west. To place a windbreak at an angle through a field would be an inconvenience for farming.

Desirable wind reduction occurs over the greatest area when density is approximately 40 to 50 percent. For example wind speed is reduced by 20 percent at 12 H when density is 30 percent, at 27 H when density is 50 percent and at 15 H when density is 100 percent. High density windbreaks create a greater reduction in wind speed close to the windbreak and cause high snow drifts close to the windbreak. Low density windbreaks do not cause as great a reduction in wind speed, but the wind reduction and snow distribution extend over a greater distance, thus benefitting a larger crop area.

Windbreak density is affected by crown density of tree species used, spacing between trees in a row, number of rows and spacing between rows. For field windbreaks it is possible to achieve the optimum density for wind reduction and snow dispersal with one row of deciduous trees. For example, Siberian elms, which have a very dense crown, should be spaced approximately 15 to 20 feet apart. Green ash have a more open crown and should be spaced approximately 10 feet apart. The ideal tree for a field windbreak is tall, has a narrow, upright crown, moderate crown density, grows rapidly and is resistant to insects and diseases. More than one tree row may be needed if only tree species with open crowns are available for planting or if pest or environmental conditions are likely to kill trees, creating gaps in the windbreak.

Field windbreaks are more effective when a pattern of several parallel windbreaks are established rather than just a single, isolated windbreak (Darnhofer 1982, Woodruff 1956).

## FARMSTEAD WINDBREAK DESIGN

Farmstead windbreaks are designed quite differently from field windbreaks. Farmstead windbreaks are usually intended to stop snow close to the windbreak and to greatly reduce wind velocity over a relatively short distance across the farmstead. Given these requirements, much denser windbreaks are needed. They commonly include 4 to 8 rows. For example an 8-row farmstead windbreak might include a shrub row on the outside, followed by three rows of hardwood trees, then four rows of conifer trees (Sholten 1988). Hardwood trees usually grow faster than conifers, giving more immediate shelter. On some sites the conifers often catch up to the hardwoods in total height. When that occurs, it may be appropriate to remove the hardwoods, if that space is needed for other purposes.

A 4-row windbreak may be used where there is not adequate space for 8 rows. A 4-row windbreak commonly has four rows of conifers or one row of shrubs and three rows of conifers.

Farmstead shelterbelts should usually be located 100 feet from the area needing protection. If located too close, snow will pile up in the area needing protection. If located too far away, the farmstead will not receive adequate protection from wind and snow drifts.

Where blowing snow is a problem, the shrub row should be located approximately 70 feet upwind from the nearest row of trees. Shrubs are very effective at catching snow. If shrubs are located too close to conifer trees, they will cause large snow drifts among the conifers which may lead to severe limb breakage. Spacing of shrubs with a row varies with the species, but is often about 6 feet.

Spacing between tree rows varies with the species and site quality, but is commonly about 20 feet. Spacing between trees within a row also varies with the tree species and site quality, but is often 10 to 20 feet. Much closer spacings were used in the past, but these usually led to crowding and subsequent death of trees, self-pruning of lower branches or susceptibility to pests.

## PLANTING AND MAINTAINING WINDBREAKS

There are several types of planting stock that may be used for windbreaks depending on the trees species, site and budget. When seed is sown in the nursery beds and grown for 1 to 3 years and then lifted for field planting, the planting stock is known as seedlings. When seedlings are grown in the seed bed for a year or two, then lifted and replanted in new beds and allowed to grow another one to three years, they are called transplants. Transplants produce larger seedlings with larger root systems, which usually result in better survival. Conifers are sometimes available as transplants. Container-grown seedlings are produced by sowing seed directly in a container. Some containers are biodegradable, but others are not and trees must be removed from them before field planting. Conifers are more commonly available as container-grown stock than are hardwoods. Potted stock is not necessarily container-grown. Potted stock is often larger stock that has been lifted from the nursery bed and placed in a pot prior to being sold. Balled and burlapped stock is larger trees that have been dug from the nursery with soil intact and wrapped with burlap to hold the soil around the root system. The expense of balled and burlapped stock is usually prohibitive for windbreaks. The most common recommendation for windbreak stock is to use bare-root stock for hardwoods and container-grown stock for conifers (Scholten 1988). Hybrid poplars are most commonly planted as cuttings.

Prior to planting windbreak trees, competing vegetation must be killed by plowing and disking or herbicide application.

Trees may be planted with hand tools such as a planting bar or spade, with a tree planting machine towed behind a tractor, or with a tractor-mounted auger. The auger method usually results in the best survival and early growth (Scholten 1988).

Weed control is needed for several years after the trees have been planted to ensure their survival and fast growth. On dry sites weed control may prove beneficial if carried out indefinitely.

On dry sites irrigation will greatly increase tree survival and growth. Flood and drip methods are most common. Applying mulch around trees at the time of planting is very effective in conserving moisture and will minimize the need for irrigation (Scholten 1988).

Insects, diseases and small mammals can be serious pests of windbreak trees. Concern about potential pests is often a limiting factor in species selection. Tree species used for windbreaks are often different from those used for forest plantations, because windbreak trees must meet certain criteria related to crown density and shape, and be able to survive on very harsh growing sites. Because of the harsh growing sites, trees are often stressed and, therefore, susceptible to pest damage.

In a windbreak each tree serves an important function. Pests that cause defoliation, limb breakage, deformity or tree death affect windbreak density and, therefore, a windbreak's effectiveness. Because of the unique value of each tree, a lower level of pest damage is tolerable in windbreaks than in forest plantations.

## IMPORTANCE OF ENTOMOLOGISTS

Entomologists provide a valuable service to rural America because of their knowledge and research ability relating to insect pest of windbreaks. There is a need to continue study of insect pests on nursery stock and established windbreak trees. Insects may kill or damage nursery stock, reduce height growth, deform trees, reduce crown density, carry diseases and kill established trees. As entomologists you can help identify pest resistant trees, suggest cultural practices that will minimize risk, and recommend control measures that will stop or reduce insect damage.

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# Effects of Windbreaks on Local Distribution of Airborne Insects[1]

Gordon M. Heisler and Mary Ellen Dix[2]

Abstract.--Both vegetative and artificial windbreaks modify wind flow streamlines, reduce horizontal windspeeds, and alter the turbulence structure of wind. These changes increase aerial density of insects of many taxa. Increases of up to approximately 30 times density in the open have been measured, but increases of two to eight times are more common.

## INTRODUCTION

Windbreaks are structures or vegetative arrangements designed to reduce wind velocity. A multiplicity of windbreak effects almost always occurs, some of which are benefical to people and some of which are not. Their immediate physical effect on the nearby environment leads to complex interrelationships with plant and animal communities. All positive and negative effects of windbreaks (Brandle et al. 1988) should be considered when designing and managing a windbreak.

Windbreak effects on microclimate that increase crop growth, reduce fruit damage, control snow, or save energy for heating buildings also may lead to modifications in abundance and distribution of insects. Windbreaks influence beneficial insects, including pollinators of crops and natural enemies of crops, as well as pests of agricultural crops.

Vegetative windbreaks influence insect distributions by: providing overwintering sites, serving as alternate hosts, and modifying wind and other meteorological variables. This paper concentrates on the influence of windbreaks on insect distributions by modifying wind flow. Much of the research evaluating this influence was reported between 1965 and 1972 by T. Lewis and his colleagues at the Rothamsted Experiment Station in Great Britain (Pedgley 1982, Pasek 1988). Since 1972 knowledge of windbreak aerodynamics has increased as a result of field and wind-tunnel measurements with fast-response sensors and data processing instrumentation, at times combined with numerical modeling techniques (Heisler and DeWalle 1988, McNaughton 1988).

Lewis and his colleagues at Rothamsted carried out a series of experiments in which aerial insect density was determined by suction traps placed upwind and downwind of various windbreaks. They used artificial windbreaks between 0.91 m and 2.44 m tall, as well as hedge and tree windbreaks. They measured windspeed and direction in the open and often at trap locations. They usually located traps and made wind measurements at several distances measured in units of windbreak height (h) from the windbreak up to 12 h leeward. Measurements were usually at a height of 0.4 h. Wind measurements in comparison to other measurements will be discussed, then insect distribution will be presented.

## EFFECTS OF WINDBREAKS ON AIRFLOW

The patterns of mean windspeed around windbreaks were known by the mid 1960's, when van Eimern and his coauthors published an exhaustive review of world literature on most aspects of windbreak influences (van Eimern et al. 1964). That work was available when most of the studies concerning windbreak effects on insect distributions were conducted at Rothamsted. In the following, only aspects of wind flow that are not included in van Eimern et al. (1964) are given specific references.

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1 Paper presented at the conference "Insects of windbreaks and related plantings: distribution, importance and management". Entomological Society of America 1988 National Conference, Louisville, KY, December 6, 1988.

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The least complicated windbreak situation occurs when wind direction is perpendicular to the centerline of a uniformly porous vertical fence that is sufficiently long, relative to height, that it can be assumed to be infinitely long. According to Naegeli (1953), a windbreak at least 11.5 h long and an infinitely long windbreak will create similar influences on perpendicular winds along their centerline (perpendicular bisector). At the ends of windbreaks, wind tends to curve inward toward the protected zone. With short windbreaks, the wind curving around the ends of the windbreak limits the length of the reduced windspeed zone.

Simple fences or screens have been used in much of the research on windbreak effects. Fence windbreaks are easy to erect over a selected surface and to model in wind tunnels. When wind approaches from a perpendicular direction, flow at fence barriers and natural windbreaks is similar, provided that the natural windbreaks are relatively narrow -- with height greater than, or at least not much less than, width. Fences are also of special interest in studying effects of wind on insect distributions because they permit the separation of wind effects from the biological effects of natural windbreaks.

Wind flow is affected by a windbreak in three ways: 1) streamlines are modified; 2) mean horizontal windspeeds are reduced; and 3) the turbulence structure of the wind flow is altered. The distribution and activity of insects may be affected by all three windbreak influences.

## Streamlines

The streamline effect is created as high pressure on the upwind side of the windbreak forces some of the flow over it, resulting in upward-bending streamlines upwind of the barrier, compression of streamlines above the barrier, and downward-bending streamlines downwind of the barrier (fig. 1). The streamlines follow the average path of air parcels. The instantaneous direction of a parcel may deviate considerably from the streamline.

Air flowing fast over the barrier can be visualized as separated from air below and leeward of the barrier by a streamline or narrow zone that begins just above the barrier (fig. 1). If wind direction is perpendicular to the barrier, the separation streamline approaches ground level at about 8 h to leeward. With windbreak porosity up to about 30 percent, there often has been noted some degree of recirculating flow toward the barrier near ground level below the separation streamline as depicted in fig. 1. The figure is merely a schematic representation of streamlines in the flow; generally, return flow in the recirculation zone would be weaker than the downwind flow above.

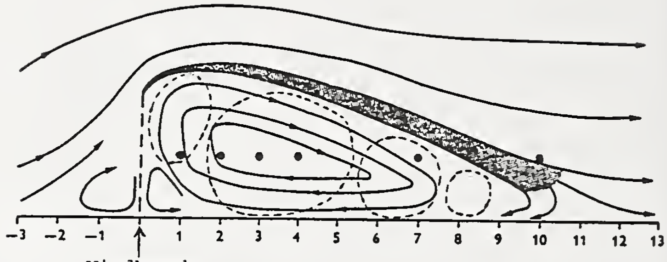


Figure 1.--Streamlines of mean flow over a windbreak (From Lewis and Dibley 1970). Flow separates in the shaded area. Dots indicate measurement points of Lewis and Dibley (1970); see text.

Lewis and Dibley (1970) measured mean vertical wind angles at 0.5 h at several distances (locations marked by dots in fig. 1) downwind of two fences with different-sized openings but equal porosity of 39 percent. The mean wind direction (streamline direction) at the different distances was downward at angles ranging from 10 to 18 degrees, but frequent fluctuations between upward and downward were recorded. Fluctuations were greater at the fence with the larger openings.

## Mean Windspeeds

Mean horizontal windspeeds are altered by a combination of the pressure and streamline patterns, absorption of momentum by the windbreak, and conversion of horizontal momentum to turbulent motion. The recirculation zone below the separation streamline is the region of largest reductions in mean horizontal windspeed. As porosity increases, this zone is increasingly influenced by flow through the barrier.

Above the barrier, the compression of streamlines causes windspeed (U) to be in excess of the approach speeds ($U_o$) at the same height. The increase in windspeed is greater with a solid or very low-porosity barrier than with a high-porosity barrier.

Most parameters commonly used to describe windbreak effects are based on the profile of relative windspeed, $U/U_o$, near the ground upwind and downwind of windbreaks. The profiles are plotted either as $U/U_o$ versus distance, or as windspeed reduction ($1-U/U_o$) versus distance (fig. 2). Horizontal profiles of $U/U_o$ around windbreaks usually change little between ground level and 0.4 h (Heisler and Dewalle 1988).

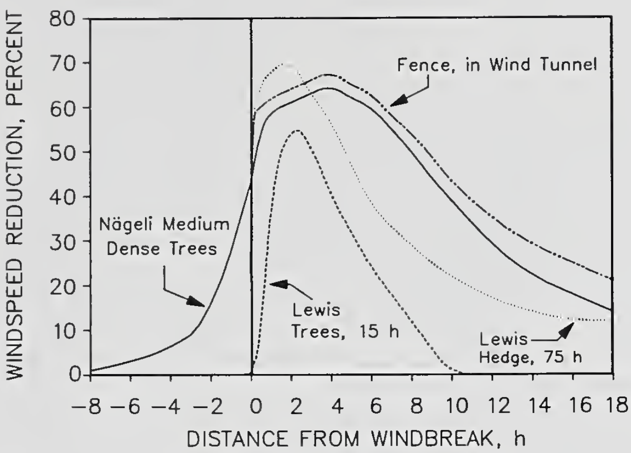


Figure 2.--Windspeed reduction ($1 - U/U_o$) in percent for a fence in a windtunnel (Raine and Stevenson 1977), a medium-dense tree windbreak (Naegeli 1946), a 75-h-long hedge (Lewis 1969), and a 15-h-long tree windbreak (Lewis 1970).

The extent of windbreak influence is often characterized by the distance ($d_p$) over which relative windspeed is less than a certain value, usually 0.80 ($d_{p80}$). Reports of wind measurements from Rothamsted include data for 15 different windbreaks from which $d_{p80}$ can be derived. In most other studies of windbreak effects, values of $d_{p80}$ are between 10 and 20 h for windbreaks with porosity of 60 percent or less, whereas in the Rothamsted measurements, $d_{p80}$ ranged from approximately 5 to 10 h. The low values of $d_{p80}$ evidently occur because of the limited length of windbreaks used by Lewis combined with the wide range of wind directions over which data were collected. The windbreaks used by Lewis ranged in length from 10 to 75 h, but in only one case, that of the 75-h-long hedge in fig. 2, was windbreak length longer than 30 h. The wind-tunnel results in fig. 2 indicate reductions with constant perpendicular wind direction, a condition only infrequently approximated in the atmosphere.

Even with windbreaks that are essentially infinitely long, as wind direction departs from perpendicular, $d_p$ measured perpendicularly is reduced. For fence windbreaks, direction effect on $d_p$ seems larger than expected on purely geometrical reasoning, whereas with vegetative windbreaks, where width is significant relative to height, the direction effect seems to be smaller (Heisler and DeWalle 1988). This is at least partly caused by the increases in effective width of vegetative windbreaks as wind approaches more obliquely; this increases the overall density, particularly for otherwise low-density structures.

As windbreaks become shorter, oblique wind angles increasingly reduce $d_p$, because for more downwind points, wind increasingly misses the windbreak entirely. The measurements of Lewis were made with "wind directions" up to either $40^o$ or $45^o$ from perpendicular. Usually measurements were made over a number of sampling periods (often of unspecified length) and the results averaged. Wind direction was recorded continuously on a strip chart (Dibley and Lewis 1970) that might have been used to estimate either the maximum range of wind directions or the mean direction over each sampling period. Apparently, however, the range of wind directions was usually reported as the range of mean wind directions over several sampling periods. With wind directions $45^o$ from perpendicular, points beyond 10 h downwind would be completely unprotected. In fig. 2, we see that a 15-h-long tree windbreak provided a $d_{p80}$ of only 7 h in Lewis' experiments and showed no effects beyond 10 h. A long hedge (75 h) provided a $d_{p80}$ of approximately 10 h and showed some reduction out to perhaps 25 h. Fences 20 h long provided values of $d_{p80}$ between approximately 5 and 7 h in Lewis' experiments.

In other respects too, the pattern of windbreak effects on wind flow observed by Lewis differs from other measurements. His observation that maximum reductions for dense barriers occurred closer to the barrier is common to other measurements, but the distance to points of maximum reduction are generally smaller than in other measurements around windbreaks of comparable density. Lewis reported generally larger minimum relative windspeeds (smaller maximum reductions or "shelter") than reported in other studies (fig. 3). In one study of insect distributions, Lewis (1967) used a position 10 h leeward as the unsheltered zone. In many studies by other workers, windbreak effects have been measured as far as 30 h and even farther leeward.

Another reason for generally low windbreak effects shown by the averages of Lewis' measurements may be that open windspeeds during some data collection periods were relatively low. Low windspeeds usually indicate accompanying large fluctuations in wind direction. Lewis and Stephenson (1966) found particularly small windspeed reductions at 3 and 6 h downwind of fences when open windspeeds averaged 3 mph as compared to periods with 6- to 9-mph open windspeeds.

Still another possible cause of small windspeed reductions may be the relatively rough surfaces over which winds approached the windbreaks in some experiments (Lewis 1965b). Rough surfaces increase turbulence of wind, and windbreak effects are smaller in more turbulent approach flow.

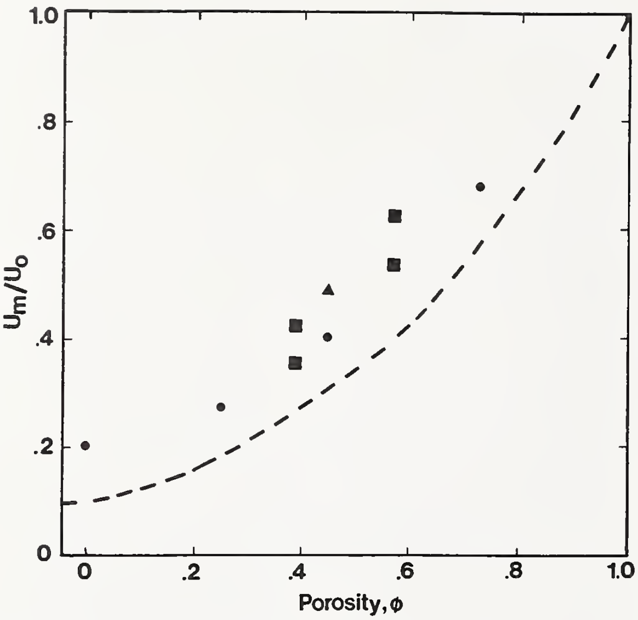


Figure 3.--Minimum relative windspeeds ($U_m/U_o$) at the 0.4-h height downwind of fences of various porosities at Rothamsted (Lewis 1965b, triangles; Lewis and Dibley, 1970, squares; Lewis and Stephenson 1966, circles). Dashed curve is estimated average of values published by eight authors from measurements at 15 different fences (Heisler and Dewalle 1988).

## Turbulence

Turbulence is usually expressed in terms of the standard deviation of wind speed or direction fluctuations in one or more of the directional components: u, along the mean wind direction; v, lateral to the mean wind direction; and w, vertically. Standard deviations of windspeed are then $s_u$, $s_v$, and $s_w$. Because the standard deviations of windspeed vary with mean horizontal windspeed, they generally are expressed relative to a reference velocity that characterizes the approach flow, such as the upwind windspeed at the height of the barrier ($U_h$) or the approach-flow friction velocity, $u_*$. ($u_*$ is an indicator of the change in windspeed with height. It is given by $u_* = 0.4 U_z/\ln(z/z_o)$, where $U_z$ is windspeed at height z above ground, and $z_o$ is a height at which windspeed extrapolates to 0. Because $z_o$ increases with surface roughness, it is often called a "roughness length".) Turbulence expressed as standard deviation of wind velocity at a point near the windbreak divided by an upstream wind velocity is indicative of relative turbulent energy in the wind. Turbulence also may be expressed relative to local windspeed at the windbreak location as turbulence intensity TI = $s_u/U$.

Turbulent energy near windbreaks is reduced in some zones and increased in others. The region below the separation streamline to the lee of windbreaks has been termed the "quiet zone" (Raine and Stevenson 1977), because turbulent energy generally is reduced relative to upstream velocity. Only $s_w$ behind solid fences has been observed to increase. Within the wake zone that begins above the top of the fence, turbulence is increased. The wake zone spreads vertically and may extend essentially to the surface beyond the end of the quiet zone at about 8 h leeward, at least with solid fences. In all zones influenced by windbreaks, the peak frequency of the turbulence is increased; that is, the fluctuations are faster than in the undisturbed wind.

In discussing the possible effects of turbulence on accumulation of insects between a fence and 7 h to leeward (within the quiet zone), Lewis (1965b) assumed a definition of turbulence that is essentially equivalent to turbulence intensity (TI=$s_v$/U). The magnitude of windspeed fluctuations (values of s) is reduced in the quiet zone, but because the local mean horizontal windspeed, U, is much reduced, TI is increased compared to the approach flow.

Lewis and Dibley (1970) lamented the fact that they were not equipped with instrumentation to measure turbulent fluctuations in wind for computer analysis. They used a wind vane recording on a strip chart and vertical anemometers to measure the frequency of upward/downward wind directions fluctuations and the standard deviation of vertical windspeed. Results were presented for points leeward of four artificial windbreaks. Windbreaks of equal porosity but with different element sizes; that is, of fine and course texture, produced significantly different numbers of fluctuations. The courser texture produced more fluctuations and up to 10 percent lower horizontal windspeed.

## OBSERVED INSECT DISTRIBUTIONS NEAR WINDBREAKS

Lewis evaluated insect density with suction traps that had horizontal circular openings 9 in. (0.23 m) in diameter. A fan pulled air through the opening at a constant rate and deposited insects in containers that changed automatically at the end of set sampling periods. The efficiency of suction traps in representing actual insect density in air varies with insect size and windspeed (Taylor 1962, Schaefer et al. 1985). Actual density could easily be underestimated by a factor of 2 if corrections are not applied. Corrections for windspeed were not found in any of Lewis's references. Recent trap effectiveness measurements (Schaefer et al. 1985) indicate significant differences from trap efficiency corrections available at the time of Lewis' measurements (Taylor 1962). These considerations suggest that some of the insect

densities may be smaller than Lewis' measurements indicate.

## Artificial Barriers

In general, insects flying over the study areas from sources elsewhere accumulated behind artificial barriers in locations where measured reductions in mean horizontal windspeed were greatest (Lewis 1965b, 1965c, 1966a, 1967; Lewis and Dibley 1970; Lewis and Stephenson 1966). Hence, peak insect accumulations tended to be greatest behind either solid or low porosity (for example, 25 percent porous) windbreaks (fig. 4); peaks usually occurred at the distance from the fence at which the maximum wind reduction occurred, that is, closer to more dense windbreaks; and peak accumulations were closer to windbreaks with more oblique winds. Peak accumulation of flying insects on the leeward side of artificial windbreaks usually was 2 to 3 h horizontally from the windbreak (Lewis 1966a, 1967). None of the experiments strongly demonstrated accumulations beyond about 7 h leeward of artificial barriers, probably because of their relatively small $d_p$. Patterns of accumulation measured in h units were similar regardless of windbreak height (Lewis 1967), as would be expected, given that patterns of windbreak effects on wind are generally similar when measured in h units.

Maximum vertical height of accumulations of flying insects 0 to 2 h leeward of artifical windbreaks increases with decreased porosity of the windbreak. Insect abundance increases up to heights of 1.5 to 2 h behind a 45 percent permeable windbreak, because wind flow is directed up and over the windbreak (Lewis and Stephensen 1966, Lewis 1967). Vertical abundance of strong fliers and large insects, such as Staphylinidae and Biblionidae, did not differ significantly between sheltered and exposed sites at windspeeds between 0.9 to 2.4 m/s, because they were able to direct their flight at these windspeeds. Vertical profiles of weak fliers, such as Cecidomyiidae and Psychodidae, varied significantly between sheltered and exposed sites. They were significantly more abundant in sheltered sites (Lewis 1967).

Peak insect accumulations to leeward of windbreaks, as a multiple of density at upwind control points, ranged from about 1.4 for aphids (Aphididae) (Lewis and Stephenson 1966) to about 27 for flower flies (Syrphidae) (Lewis 1965b), but were commonly between 2 and 8. The difference in accumulations by different taxa was generally related to insect size and air speed, though there were examples where strong fliers accumulated relatively more than weak fliers (Lewis and Dibley 1970). The difference with taxa may have been partly a function of duration of flight, those that land more often or for longer periods being less affected by wind (Lewis 1966a). Fig. 4 shows relative accumulations for

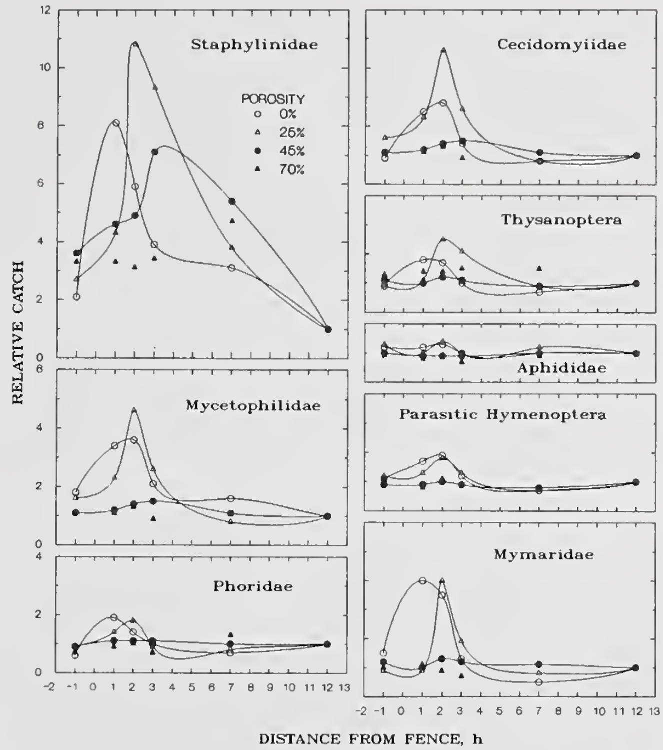


Figure 4.--Distribution of relative catch of several taxa of insects downwind from fences of different porosity (data replotted from fig. 2, Lewis and Stephenson 1966). Data points for 12 h to leeward not measured but assumed the same as those at 12 h windward.

several taxa in one study and Pasek (1988) provides further review of accumulations by specific taxa.

Several of the Rothamsted studies sought to explain the reason for the insect accumulations. A general conclusion was that insects accumulated primarily as would inert objects such as snow (Lewis and Dibley 1970, Lewis and Stephenson 1966). Lewis and Dibley (1970) suggested that insects tend to arrive in the low-windspeed zone leeward of windbreaks by a diffusion process through the shear layer that exists along the separation streamline from the top of the windbreak (fig. 1). Insects then would become trapped in the circulation bubble (fig. 1) between the windbreak and about 8 h leeward. The recirculation bubble effect would apply only to dense windbreaks, because the recirculation flow toward windbreaks evidently disappears with windbreaks of porosity greater than approximately 30 percent. Whether insects responded to reduction in mean windspeed or to reductions in wind fluctuations; that is, turbulent energy, is not clear. Because the quiet zone of reduced turbulent energy extends to about 8 h leeward, at least with perpendicular winds, measured insect accumulations were probably always within zones of reduced turbulent energy.

Windbreak effects on insect distribution depended on appoach-wind conditions. The accumulation zone of some taxa moved closer to the windbreak as windspeed decreased (Lewis and Stephenson 1966). Though Lewis and Stephenson suggested that this was probably because insects were able to fly toward the fence in light winds but carried leeward in stronger winds, it may have resulted from the windbreak effect becoming more limited with more variable wind conditions. Because diurnal windspeeds tend to be higher than nocturnal windspeeds, spiders and day-flying aphids accumulate further leeward than night-flying cecidomyids and psychodids. Insect abundance in, and size of, the accumulation zone is larger when the wind blows perpendicular to the windbreak, than when the wind blows from a 45 degree angle (Lewis 1966a). This, again, is a result of larger windbreak effect with larger winds.

The existence of insect accumulation zones near artificial barriers was verified by observations of crop damage. For example, the aphid that vectors turnip mild yellows virus apparently accumulated leeward of a 1-m (3-ft) fence (45 percent porosity) and increased the virus on crops there (Lewis 1966b). A similar fence led to severe damage to a lettuce crop by the lettuce-root aphid (Lewis 1965c).

### Tree and Hedge Windbreaks

Accumulation patterns for flying insects leeward of hedgerows and windbreaks are similar to those leeward of artifical windbreaks. However, this similarity may not always be apparent because living windbreaks are composed of a variety of plant species and vary in width, height and density not only within a windbreak,but also between windbreaks. Thus, permeability to wind and the size and shape of the sheltered zone varies within and between windbreaks.

Behind a 1.7- to 2-m-tall hedgerow, accumulations extended to about 10 h, somewhat farther than for a tall tree row (Lewis 1970) or the artificial windbreaks. The relatively long length of accumulation zone is undoubtedly related to the longer length of the hedge relative to its height and resulting longer dp (fig. 2).

Living windbreaks provide food and shelter not only to the insect fauna associated with trees, shrubs, grasses, and other vegetation in the windbreak (Dix 1987, Dix et al. 1987), but also to insects associated with crops that migrate to the windbreaks for food and shelter (Lewis 1969, 1970; Bowden and Dean 1977). For example, adult cabbage-root flies aggregate at hedgerows probably to feed on the flowers (Hawkes 1973). In California, adult parasites of a prune leafhopper (Erythroneura elegantula Osborn) migrate to windbreaks and neighboring plantings of French prune trees and blackberry vines where they overwinter in an alternative leafhopper host (Wilson et al. 1989). Insects that ultilize the windbreak tend to accumulate in the sheltered zones surrounding the windbreak, increasing its richness and diversity (Lewis 1969,1970, Bowden and Dean 1977).

From a study with four suction traps near a 7-m-tall hedgerow, Bowden and Dean (1977) concluded that the hedgerow effect on wind had a negligible influence on insect distributions. A trap adjacent to the west side of the hedge caught the most insects regardless of wind direction, and a trap at 3 h to the east generally caught the least, even when downwind. The hedge had a large number of plant species, whereas the trap at 3 h was in an agricultural crop and only one species was present. Bowden and Dean concluded that floristic diversity was the dominant influence on the distribution of insects, even for insects that did not have their source in the hedgerow. However, the apparently small influence of wind reductions may have been caused partly by ambient wind conditions during the measurements. Windspeed in the open was either fairly low or, when higher, tended to parallel the hedge. Although windspeed at the traps was not measured, the traps adjacent to the hedge were quite close, and there were probably substantial reductions in windspeed regardless of wind direction.

## MANAGEMENT OF INSECT DISTRIBUTION WITH WINDBREAKS

In addition to reviewing the effects of single windbreaks on insect distributions, we searched for information on the actual use of windbreaks to influence insect distribution. Windbreaks are used to increase the area foraged by honeybees and to regulate aphid distribution in crops.

Windbreaks reduce average wind velocities in orchards and can increase insect pollination and fruit set. In the Netherlands, fruit trees planted in a sheltered zone six to ten times the height of the windbreak produced more apples and had slightly larger diameters than those planted in unsheltered areas. Yield of apples and pears behind a windbreak increased by 11 to 73 percent and 120 percent, respectively (Van Rhee 1958). Some of this increase in yield can be explained by increased activity of pollinators in the sheltered area. Visitations by honey bees and blossom set on apple trees were higher in the sheltered area 0 to 9 h behind a 3-m high core-netting windbreak in Great Britain (Smith and Lewis 1972).

Movement of aphids on air currents and their subsequent deposition and movement in crops, especially leeward of windbreaks, has been extensively reviewed in numerous publications (Lewis 1965a, Pedgley 1982, Dean and Luuring 1970, Taylor and Johnson 1954, Pasek 1988). Migrating aphids tend to accumulate on the edge of fields and in the sheltered zones around windbreaks. Subsequent generations move through

the field on air currents flowing through and above the crops. Early surveys to detect the aphids and predict the size of subsequent generations, and early insecticide applications should be concentrated in these sheltered zones where the aphids initially accumulate (Lewis 1965c).

The basic pattern of insect accumulation leeward of houses and other urban structures should be similar to those of artificial and living windbreaks. Trees scattered throughout residential neighborhoods along streets and in yards have a substantial impact on windspeeds. The effects of trees combined with the effects of buildings reduced mean windspeeds approaching several sample houses by up to about 70 percent in one study, but there were larger reductions just to the immediate lee of structures (Heisler 1989a, 1989b). Like living windbreaks, the size and shape of the sheltered zone should vary within and between sites. Aphids, scales, gall-making insects, mosquitoes, flies, migrating Lepidoptera larvae, night flying moths, and other weak flying insects should accumulate in this zone. However, examples in the literature are rare because wind flow around urban windbreaks is not fully understood and it is difficult to relate insect distribution to these wind currents (Heisler 1989a, 1989b).

## CONCLUSIONS

Current understanding of windbreak effects on local insect distribution still relies heavily on the measurements with suction traps made by Lewis and his colleagues at Rothamsted in the 1960's. Insect accumulations were generally observed within about 7 h leeward, a region where the windbreak reduces both windspeed and turbulent energy relative to wind in the open.

Flying insects of many orders have been observed to accumulate in sheltered zones near windbreaks. Migrating aphids, cecidomyids (gall midges), and psychodids (moth flies) are deposited like inert objects along with spiders in the sheltered areas around windbreaks. Honeybees, large Coleoptera, and other species direct their flight toward the windbreaks. These insects utilize the windbreak itself for food, shelter, and forage, and direct their forage flights through the sheltered areas where windspeeds are lower. Too, they may be attracted to tall objects or other insects in or near the windbreaks.

Since the 1960's when most of the studies of insect distributions around windbreaks were conducted, knowledge has accumulated, particularly regarding the structure of turbulence in the vicinity of windbreaks. The knowledge gained more recently suggests that insects respond more to mean horizontal windspeeds than to differences in turbulence, although the effect of turbulence on insect distributions is not entirely clear. Insects aggregate more in zones of lowest windspeeds behind dense barriers than behind less dense barriers, apparently in response to the lower windspeeds behind the dense barriers, even though turbulent energy is greater behind the dense barriers.

Almost all studies of windbreak effects have shown greater windbreak influences on wind than in the measurements of Lewis and colleagues. This is largely caused by the relatively shorter length of most of the Lewis windbreaks. However, the Lewis measurements of wind and insect accumulations may be representative of typical field conditions. The effect of short windbreaks tends to be countered by natural variablility of wind directions over a season. Lewis usually made measurements over a 90° angle (45° to each side of perpendicular), which tend to overestimate the seasonal average effect of a windbreak, because wind direction in most locations is even more variable. For example, in Topeka, Kansas, wind direction in summer tends strongly from the south. But even here, long-term weather records indicate that wind direction would be within 45° of perpendicular to an east-west windbreak (either from the north or south) only about 56 percent of the time from April through September.

In future research on insect distribution near windbreaks, investigators might give greater consideration to micrometeorological variables other than wind that influence the energy balance of the insects. Insect body temperature influences takeoff and flight patterns. Air temperature and radiant energy input, both of which may be affected by windbreaks, influence body temperature and windspeed. Modern anemometry and signal processing could provide turbulence information that would provide considerable insight into the aerodynamics of the problem. Another need is a trap design that accurately measures actual density of insects with no dependence on windspeed.

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# Effects of Windbreaks on Overwintering of Boll Weevils[1]

J. E. Slosser[2]

ABSTRACT.--The relationship between boll weevils, overwinter habitat and cotton is discussed. Field windbreaks planted between 1935 to 1942 are implicated as one reason for original establishment of boll weevils in the northern Texas Rolling Plains. A study was initiated in 1977 to determine effects of windbreak management on overwinter survival of boll weevils. Selective tree row removal with subsequent disking between remaining rows reduced the available leaf litter and altered temperature profiles in managed areas as compared with untreated check areas. This type of management reduced the number of fall-migrating weevils that selected and remained in the habitat, reduced winter survival, and hastened spring emergence. Windbreak management guidelines to reduce the economic threat of boll weevils to adjacent cotton culture were developed from this study.

## INTRODUCTION

The boll weevil, Anthonomus grandis Boheman, is the key pest in both irrigated and dryland cotton, Gossypium hirsutum L., in the Texas Rolling Plains. However, the weevil is generally the only pest of annual consequence in dryland cotton, which comprises about 95% of the cotton acreage.

Boll weevil emergence from overwintering habitat begins in early spring and continues through early summer. Early emergence is suicidal, but those weevils that emerge after mid-June initiate the summer infestations in cotton. Four to five generations are completed during the growing season. Boll weevil adults enter diapause in the fall, and then they migrate from cotton to overwinter in broadleaf litter.

The boll weevil had extended its range into the Texas Rolling Plains by 1922, but infestations were sporadic until the early 1950's. The initiation and continuation of severe problems in several northern Rolling Plains counties has been linked to the windbreak plantings made from 1935 to 1942 as part of the Prairie States Forestry Program (Bondy et al. 1923, Bottrell et al. 1972a, Slosser and Boring 1980). About 1400 miles of windbreaks were planted in 13 counties (Fewin and Slosser, unpublished data), but there were no apparent maintenance programs initiated after the original efforts to establish the tree plantings. As a result leaf litter and other debris had probably accumulated sufficiently by 1950 to allow large numbers of weevils to survive the winters.

The relationship between boll weevils and windbreaks is an example of man's modification of the environment to the benefit of the pest. The original windbreak plantings can not be held responsible for the current weevil situation because most of the windbreaks have badly deteriorated. But, these tree plantings allowed the weevil to more rapidly extend its range and become permanently established in an environment very unlike that of its subtropical origin.

My research has lead to the development of management guidelines which should allow the coexistence of cotton and new windbreaks without further exacerbation of the weevil problem. The objectives of this report are to discuss how windbreak management influences habitat quality and winter survival of boll weevils.

## BOLL WEEVILS AND OVERWINTERING HABITAT

Adkisson et al. (1965) surveyed the habitat types selected by diapausing weevils in the western Rolling Plains adjacent to the caprock escarpment. They found that leaf litter associated with cottonwood, sand shinnery oak, salt cedar, hackberry, and shelterbelts supported the highest num-

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bers of overwintering weevils per acre. In another study, Boring (1972) surveyed the overwinter habitat preferences of diapausing weevils in the northeastern Rolling Plains. He found that shelterbelts supported the highest numbers of overwintering weevils per acre, but western soapberry, sand shinnery oak, and other types of broadleaf litter also supported high numbers.

Bottrell et al. (1972b) reported that the number of weevils in overwintering habitat was directly related to the distance of the habitat from cotton. They found three times as many weevils in habitat adjacent to cotton as compared with numbers in habitat that was 0.5 miles from cotton, and habitat that was 1.0 to 1.5 miles from cotton had very few overwintering weevils. Rummel and Adkisson (1970) reported a similar relationship; the closer cotton was to overwintering habitat the higher the percentage of infested fields. They found that 20% of the fields adjacent to winter habitat were infested by mid-August as compared with only 5% of those fields that were > 0.5 miles from habitat.

The actual economic impact of overwintered weevils on cotton yield is dependent on several factors. In the Rolling Plains, rainfall is a more limiting factor than insect pests in dryland cotton in most years. However, when overwintered populations survive in high numbers, I have seen the cotton crop adjacent to windbreaks completely destroyed by weevils. On the other hand, when summer drought is severe, insecticidal control of even moderately heavy weevil populations often does not increase yield. Slosser and Boring (1980) reported that cotton yields in fields adjacent to windbreaks were reduced by about 36% in 1975. Thus, the economic impact of the weevil/windbreak interaction in dryland cotton (but not irrigated cotton) is influenced by the actual survival rate of overwintered weevils and by the summer growing conditions.

## WINDBREAK MANAGEMENT PROJECT

### Materials And Methods

A study was initiated in 1977 in a windbreak that had been planted in 1939. The shelterbelt was ten tree rows wide and had a deep accumulation of leaf litter. The shelterbelt was divided into six plots, each 200 ft. long. Seven tree rows were removed in three of the plots, and the trees rows were left intact in the other three plots. The study was designed as a paired comparison of managed versus unmanaged plots with three replications. The tree species involved and other details of the study were described by Slosser et al. (1984). Wiedemann et al. (1979) compared the costs of tree removal associated with manual cutting with chain saws versus the use of a low-energy grubber, originally developed for clearing mesquite from rangeland. The original spacing of 10 ft. between tree rows was increased to 20 ft. between each of the three remaining rows after tree removal. This spacing allowed disking in the managed plots each fall to destroy any litter accumulations between tree rows.

Because of very cold winters and hot, dry summers, natural boll weevil populations did not occur in the plots during the fall of 1979, 1980, or 1981. Therefore, boll weevils were artificially placed into each plot in late fall of these three years. Native boll weevils did migrate into the plots during the fall of 1982. Six leaf litter samples, 1 $yd^2$ each, were collected from each plot during December 1982; and the number of weevils were counted to determine habitat preference.

To obtain weevils for the study, egg-punctured squares were collected from plants from mid-September to late October. The squares were maintained in the laboratory under controlled light and temperature conditions. A photoperiod of 11:13 L:D and rearing temperatures ranging from $50^{\circ}$-$80^{\circ}$F., depending on the stage of development, ensured that most of the weevils entered diapause. The weevils were then placed on the litter surface in the plots and immediately covered with a pyramid-shaped screen cage. Depending on the year, three or four cages were placed in each plot, and the number of weevils placed in each cage was 108, 125, and 175 in 1979, 1980, and 1981, respectively.

A glass collecting jar on top of the cage was inspected weekly for adult weevils from April to July. Overwinter survival rates and spring emergence patterns were used as biological indicators of habitat suitability as influenced by management.

A two-probe soil thermograph was used to record litter temperatures at the leaf litter-soil surface interface each year. Anemometers were used to measure wind velocity 6 ft. above the soil surface. Open field velocities, on the windward side of the shelterbelt, and check plot and managed plot velocities, on the leeward side of the shelterbelt, were monitored on several occasions in the spring of 1978. A complete description of all experimental methods was given by Slosser et al. (1984).

Overwinter survival data were analyzed with paired t tests, analysis of variance, and calculation of exact probabilities.

### Results

Percent overwinter survival in the unmanaged check plots was higher than that in the managed plots in each year of the study. Percent survival ranged from 0.20 to 1.44% in the unmanaged, check plots and from 0.00 to 0.82% in the managed plots. The three-year average survival in the check plots was 0.56% as compared with 0.21% in the managed plots. These values were significantly different at the 0.054 level of probability.

The spring emergence period continued longer into the summer in the unmanaged check plots as compared with emergence periods in the managed

plots in all three years. In 1980 emergence lasted from 9 April to 11 June in the check plots and from 26 March to 5 June in the managed plots. In 1981 emergence lasted from 10 April to 15 May in the check plots, but weevils only emerged on 10 April in the managed plots. There was no emergence in the managed plots in 1982, but emergence in the check plots occurred from 14 April to 9 July in the check plots.

Leaf litter samples taken in December 1982 indicated there were 3.4 times as many weevils in the check plots as compared with numbers in the managed plots. There was an average of 1.7 weevils/$yd^2$ in the check plots and 0.5 weevils/$yd^2$ in the managed plots.

Leaf litter temperature profiles were altered by tree removal in the managed plots. The average monthly temperatures from November to March were 3.6$^{o}$F higher in the check plots as compared with litter temperatures in the managed plots. Average minimum temperatures were below 32$^{o}$F in January and February in the managed plots, but freezing temperatures were not recorded in the check plots. During the spring months of April to June, temperatures averaged 2.2$^{o}$F higher in the managed plots as compared to litter temperatures in the check plots. Winter temperatures were lower and spring temperatures were higher in the managed plots.

Selective tree row removal did not substantially affect windbreak function of the managed area. For the period 7-8 March 1978, open field wind velocity on the windward side of the shelterbelt averaged 13.8 mph. Wind velocities averaged 3.0 and 2.4 mph behind the managed and check areas, respectively, on the leeward side of the shelterbelt at a distance of 138 ft. from the tree rows. At a distance of 321 ft. downwind from the tree rows, wind velocities averaged 5.8 and 4.1 mph behind the managed and check areas, respectively.

Read (1964) stated that the threshold velocity for soil movement was between 12 - 15 mph. Open field wind velocity on the windward side of the shelterbelt was in this threshold range, but leeward velocities were below the threshold. This result indicates that selective removal of tree rows did not harm the windbreak function of the managed area.

## Discussion

There were several benefits regarding boll weevil management in overwintering habitat that resulted from this windbreak study. First, there was an 84% reduction in the total amount of litter habitat. This reduction was attained by tree row removal which decreased the width of the shelterbelt by 47%. In addition, a tractor and disk could be used between the remaining three tree rows to further eliminate leaf litter. Second, tree row removal created a more open environment which allowed a slight increase in wind movement through the habitat. As a result, some leaves were undoubtedly blown from the windbreak; but more importantly, the altered environment changed the litter temperature profile. Winter temperatures were lower and spring temperatures were higher in the managed area as compared with the check area. Third, because of a poorer quality habitat, winter survival was reduced in the managed area. This reduction is attributable to a thinner layer of leaf litter and to the colder temperature conditions; the remaining leaves provided less insulation. Fourth, spring emergence patterns were altered. Spring emergence of weevils from the managed area terminated sooner than emergence of weevils from the check plots, apparently because litter temperatures were higher. Therefore, most of the spring emergence was suicidal because cotton is not a suitable host until mid-June when squares begin to form on the plants. In the managed plots, boll weevil emergence did not last until mid-June. And fifth, there were fewer weevils in the managed plots in December 1982. This indicates that natural fall-migrating boll weevils did not select the managed area in high numbers.

## Windbreak Management Guidelines

These results show that litter management in windbreaks can be used to reduce the number of weevils that select the habitat, to increase winter mortality, and to hasten spring emergence. However, effective litter management requires an active maintenance program. On outside rows, tree limbs that touch the ground must be pruned just high enough to prevent trapping of litter beneath trees on the exterior of the windbreak. Within the interior of the windbreak, tree limbs must be pruned high enough to allow passage of a tractor and disk. An additional management strategy is to only plant evergreen trees, because litter from these trees is less suitable for overwintering boll weevils than litter deposited by deciduous trees (Boring et al. 1985).

If windbreaks are managed properly, the boll weevil can be eliminated as a serious threat to adjacent cotton production.

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# Influences of Shelterbelts and Other Alternate Vegetation in Agricultural Landscapes on Invertebrate Ecology[1]

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Abstract.--Shelterbelts, windbreaks and other types of alternate vegetation confer structural complexity to agricultural ecosystems and provide protective functions to landscapes in terms of reducing wind and water erosion. Structural complexity and plant architecture can impact appreciably on invertebrate diversity, distribution and population dynamics. Shelterbelts increase both diversity and densities of some foliage and soil inhabiting arthropods. Patterns of herbaceous crops also can be manipulated to affect plant architectural diversity and invertebrate distributions. Current economic and environmental conditions suggest an increased role for shelterbelts and agroforestry systems in modern agriculture.

## INTRODUCTION

Windbreaks, shelterbelts and other types of alternate, vegetation have long been recognized as important components of agricultural landscapes (Forman and Godron 1986, Kort 1988). These vegetation types add structural complexity to agroecosystems and include: hedgerows, tree-lined shelterbelts, woodlots, strips of forests or herbaceous plants along roads and waterways which provide a variety of protective functions to agricultural lands.

The alternate vegetation, modifies environmental conditions to the extent that physical and biological characteristics of adjacent crop fields can be appreciably altered. Essentially, shelterbelts modify most microclimatic variables downwind. Where wind flow is disrupted by shelterbelts, day temperature, soil and atmospheric moisture are increased; wind velocity, night temperatures and evaporation are decreased (Forman and Baudry 1984) (Fig. 1). Ryszkowski and Kedziora (1987) have demonstrated that the solar energy interception by shelterbelt vegetation is significantly greater than adjacent crop fields. This difference is especially pronounced in spring before annual crops have been established. Information from the same study indicates that biological activity in soil and litter habitat is greater earlier in the growing season within the shelterbelts than in adjacent crop fields. This research further shows that the increased biological activity contributes to nutrient conservation by keeping minerals from leaching into lower soil strata.

Of course, shelterbelts and windbreaks greatly contribute to ameliorating the environmentally degrading effects of wind and water erosion. It has been calculated that halving the distance between shelterbelts results in a 40% reduction of erosion in clay based soils (Pihan 1976). Shelterbelts have been shown to reduce nutrients and sediment loading into waterways (Schlosser and Karr 1981). With these

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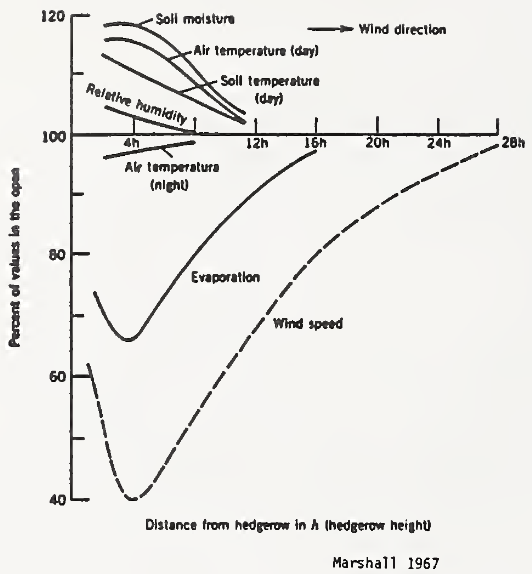


Fig. 1. **Influence of shelterbelts on climatic parameters (Marshall 1967).**

functions and others, shelterbelts, windbreaks and other types of permanent vegetation, help ensure long-term agricultural sustainability by protecting soil and water resources.

Our objectives in this paper are to review and discuss ecological characteristics of shelterbelts and other types of alternate vegetation which confer structure and complexity to agricultural landscapes. We focus on influences of this vegetation on distributions and community composition of both foliage and soil inhabiting invertebrates, and emphasize how these effects translate into impacts on insect stability, biological control and nutrient cycling processes.

## PLANT DIVERSITY AND INVERTEBRATE DYNAMICS

Pimentel (1961) proposed that increasing plant species diversity in agricultural systems results in increased diversity of insect species and reduced pest outbreaks. He argued that more diverse vegetation favor parasite and predator populations because of increased availability of refuges and greater variety of food sources. However, Tahvanainen and Root (1972) pointed out that natural enemies effects may not be sufficient to explain reduction of herbivores in diverse systems. The increased taxonomic and microclimatic complexity resulting from plant diversity was hypothesized to reduce herbivore capacity for host location and dispersion, and interfere with insects' life cycle, creating an "associational resistance" (Tahavanainen and Root 1972) between the host plant and the environment. These two approaches led Root (1973) to formulate two hypotheses to explain reduction of pest populations in diversified agroecosystems. The "Enemies hypothesis", where greater availability of nectar and pollen, greater diversity of herbivores species, and more shelter favor natural enemies populations, which reduce pest numbers. The alternative "Resource Concentration hypothesis" states that herbivores, especially monophagous or oligophagous species, have a better chance to find and remain with hosts located in pure stands, a phenomenon which tends to produce pest outbreaks.

More recently there has been a convergence of opinion that structural diversity or spatial heterogeneity are probably the most important agroecosystem characteristics affecting insect and other invertebrate population dynamics (van Emden and Williams 1974, Murdoch et al. 1982). Microclimate differences such as wind, moisture, and shade provided by corn plants were the possible factors for increase of parasitoids in a squash-corn-bean polyculture (Letourneau 1987). The structural diversity provided by corn plants was considered more important than the increase of number of species in the system. Additionally, mathematical models indicated that spatial heterogeneity is one of the conditions for successful biological control programs (Beddington et al 1978).

Most of the diversity through time, e.g., crop rotation, occur as the result of species diversity, but spatial heterogeneity in an agroecosystem can be achieved for example by different planting date or by different tillage systems. Plants at different ages may have different shape, which can interfere with herbivorous insect colonization (Thompson and Price 1977) and parasite diversity (Hawkins 1988).

The consideration of diversity of the system in a scale larger than the crop itself is also important. The inclusion of species that break the continuum of the fields such as hedge rows, may have the effect of reducing patch size and consequently influencing insect populations. Some species may have a "patch size threshold" (Kareiva 1985) below which they do not occur. Bach (1988) concluded that patch size response may be affected by non host plants around the crop.

Although there are other possible factors affecting insect communities in diverse agroecosystems (Thompson and Price 1977, Price 1984), the enemies and resource concentration hypotheses have been the major approach in studies of crop-insects diversity. Some of these studies indicate that pest reduction may be caused by predators and parasites, but resource concentration has been regarded as the main reason for pest reduction in diversified systems.

There are some proposed mechanisms to explain the effect on herbivorous insects, such as shorter tenure time (Bach 1980), lower colonization rates (Risch 1980), or lower reproductive rates (Letourneau 1986).

In a review of about 150 studies on the subject, Risch et al. (1983) concluded that, in general, resource availability is more important than natural enemies, but still 46% of the species surveyed had their numbers increased or showed varied or no response to plant diversity. Pest populations may be reduced due to plant diversification, but in some systems pests may increase (Power 1987), show no response (Letourneau 1986), or increase for some species and decrease for others (Capinera et al. 1985). Natural enemies may increase (Brust et al. 1986), decrease (Shultz 1988), or have varied response (Letourneau 1987). Finally, pests and natural enemies may increase (Marston et al. 1979) or decrease concomitantly (Andow et al. 1986).

Although there are several examples of insect pest reduction in diversified ecosystems (e. g. Altieri et al. 1978), the effect of pests and beneficial insects are too complex to be summarized in a general theory. Adding a new plant species to the system, for example, would change factors such as patch size, plant size, density, purity, microclimate, allelopathic interactions and so on, which may have different impact on different species of insects. Much of the work on the effect of plant diversity on insect populations has been examined within the context of small systems, and few studies have observed the consequence of combined factors of diversity. Generalizations are difficult to make for a range of agricultural systems (Altieri and Liebman 1986), so consideration of specific cases is the best approach to study insect population dynamics in diversified agroecosystems (Altieri and Letourneau 1982, Risch et al. 1983).

Finally, the idea that stability and diversity are intimately related has been an important paradigm in biology since the paper of MacArthur (1955), which was subsequently augmented by Odum's (1969) model of ecological succession. The concept has been criticized (van Emden and Williams 1974, Mc Naughton 1988), and the diversity-stability hypothesis has not been strongly supported by experiments, observations or models (Goodman 1975); actually some mathematical models indicated that increased diversity may even decrease stability (Rosenzweig 1971, Riebesell 1974). Connell (1978) argued that resources are unlikely to be partitioned among all species of diverse systems such as tropical forests and coral reefs under an equilibrium condition. He suggested that disturbances promotes niche diversification, allowing more species to coexist. Huston (1979) presented the idea of stability as a function of resources availability and frequence of disturbance in an ecosystem, and according to his model, a community with high frequency of disturbance in a oligotrophic system should have high diversity. In agriculture, monocultures are not unstable simply because of lack of diversity (May 1981), and there is little consistent correlation between diversity and stability, despite some examples of reduced pest outbreaks in diverse systems (van Emden and Williams 1974). Still, diversity and stability may be related but probably not in a simple, cause and effect relationship.

Murdoch (1975) presents some concepts on diversity which we think are particularly germane to landscape structure and invertebrate ecology. He points out, based on theoretical and empirical studies of predator-prey interactions, that relative stability of natural enemy-pest cycles often results when sub-populations of pests and enemies are separated in space with restricted migration between habitats. That is, spatial separation contributes to pest survival, albeit at lower densities, and consequently increases the probability of natural enemy persistance, a stabilizing mechanism in the long term. Murdoch further emphasizes that if the goal of pest management is to regulate rather than eliminate pest populations, then stability is a key parameter on which to focus. These conclusions do suggest that structural diversification should be an important issue and management strategy in pest management.

## STRUCTURAL COMPLEXITY AND SOIL INVERTEBRATES

It should be obvious from the preceding discussion that the majority of examples relating structural complexity to invertebrate distributions and diversity focus on foliage dwelling animals. Soil inhabiting invertebrates also are significantly influenced by structural complexity in agricultural landscapes, although soil invertebrates should be viewed from a somewhat different ecological perspective. Apart from the plant feeding and predatory activities of soil invertebrates - earthworms, mites collembola, and so forth - these animals are key players in organic matter decomposition and nutrient cycling processes (Edwards and Lofty 1977, Seastedt 1984). Additionally, the mobility of soil inhabiting invertebrates is often restricted compared to foliage arthropods. Then too, the sampling problems are quite different from those encountered with foliage guilds. Still, there have been a number of studies which indicate that the impact of shelterbelts and other alternate vegetation on soil invertebrates and their roles in agroecosystems can be appreciable (Ryszkowski and Karg 1976, Pollard 1968a).

Shelterbelts and other forms of vegetation which provide structure in agricultural ecosystems can modify the habitat for soil invertebrates in several important ways. The permanent vegetation complexity stabilizes

microclimatic parameters and ameliorates the influences of extreme temperature and moisture conditions. These environmental conditions not only benefit directly the invertebrates' physiologically, but also allow the development of more complex and stable foodwebs that provide resources for the invertebrates (Gorny 1968). Studies from a wide range of geographical locations do suggest that shelterbelts and other types of permanent vegetation do increase invertebrate diversity and density (Nazzi et al. 1989, Ryszkowski and Karg 1976). This pattern does, of course, have implications for pest management of soil dwelling insects, but also on soil fauna involved in decomposition and nutrient cycling processes. That is, soil invertebrates ranging from earthworms, to insect larvae to mites and collembola to nematodes, pay important functions in organic matter decomposition and nutrient cycling either directly through communition of plant litter or indirectly through effects on microbial communities (Seastedt 1984, Coleman 1985). An interesting, albeit to the authors' knowledge, unanswered question is, if numbers of these decomposer fauna are elevated by permanent vegetation, how far does this effect extend into adjacent fields?

## EFFECTS OF TREE/SHRUB VEGETATION

The main function of planted shelterbelts is to reduce soil erosion, but they also create a habitat for wildlife and affect invertebrate communities in crop fields (Slosser and Boring 1980). The trees of windbreaks provide shelter for parasitic hymenoptera (Pogue 1985) and predators (Pollard 1968), and insects in general accumulate in the sheltered zone near windbreaks (Lewis and Smith 1969). There are different leeward patterns of distribution of airborne insects (Lewis 1969), and vegetation diversity (taxonomic and structural) alters the insect fauna originating from trees (Bowden and Dean 1977). Additionally, honey bees and other nectar feeding insects accumulate near windbreaks, resulting in increased pollination (Smith and Lewis 1972).

However, windbreaks may shelter airborne pests (Lewis and Smith 1969), and provide overwinter sites for the boll weevil (Slosser and Boring 1980). In this particular case, the shelterbelt can be managed by destruction of the litter and renovation of trees (Slosser et al. 1984).

Soil dwelling insects are also affected: shelterbelts and other forested habitats provide a suitable environment for carabid beetles and spiders which invade crop fields, often moving up to tens of meters per day (Gorny 1968, Pollard 1968). During a recent study in Ohio comparing wood and crop field inhabiting soil macrofauna, we trapped larger numbers of carabid beetles in a wooded area compared to adjacent corn and small grain fields (Purrington et al. unpubl. data). There also was a set of carabid species collected in the woods which was never found in the adjacent crop fields. These taxonomic and distributional patterns were prevalant during extreme drought conditions. However, once the drought conditions subsided, the carabids were less restricted in their distributions and moved from wood to crop habitats. We have tentatively concluded that the wooded sites are important in serving as reservoirs of these fauna during times of environmental stress.

Nutrient cycling properties of agroecosystems may also be altered by the presence of shelterbelts. Paoletti (1987) and Nazzi et al. (1989) reported higher abundances of soil macro (isopods) and microfauna (mites and collembola) linked to decomposition and nutrient cycling processes in shelterbelts surrounding corn and soybean fields in northern Italy compared to open crop fields. Similarly, Ryszkowski and Karg 1976) found higher densities of decomposer invertebrates, including protozoa, in shelterbelt sites in contrast to open crop lands. Presumably, these shelterbelt sites function as sites for relatively intense soil biotic activity. Ryszkowski (1989) has further concluded, based upon water and nutrient budget studies, that shelterbelts, because of increased plant, microbial and faunal activity, can contribute significantly to uptake of nutrients, especially excess nitrate from ground water. He refers to shelterbelts as "biocenotic barriers" in this latter context.

## EFFECTS OF HERBACEOUS VEGETATION

Increased diversity in agricultural systems can be achieved by growing more than one crop simultaneously (intercropping or polyculture), the major cropping system still used in the tropics and subtropics (Hawkins 1984). Polyculture has the advantage of decreasing soil erosion, reducing risk of crop failure, providing better utilization of resources, and may reduce incidence of insects and weeds (Horwith 1985). Several examples of pest reduction in polycultures are given by Altieri et al. (1978), Cromartie (1981), and Altieri and Letourneau (1982), but probably one of the most successful case of pest reduction due to crop diversification was the control of the tobacco budworm in the Canete Valley, Peru (Hambleton 1944). Increase of pest populations may also occur under polyculture conditions: for example, soybean loopers are more abundant in soybean fields near cotton fields, probably because of nectar provided by cotton plants (Beach and Todd 1986).

Weeds within or surrounding crops also increase plant spatial diversity, with effects on invertebrate populations. Weeds may reduce incidence of aphids (Smith 1969) and other pests (Altieri and Whitcomb 1979), and may cause increased parasitism levels on orchard pests (Leius 1967). But weeds within the crops may

also increase incidence of pests (Latheef and Irwin 1979), and vegetation surrounding the crop fields may be a source of pests (Tonhasca 1987) and natural enemies (Altieri and Whitcomb 1979).

For several years, we have been experimenting with growing corn or maize in polyculture with annual and perennial crops in order to increase structural complexity within cropping fields. In one system, we have established alternating strips (each of 5 m width) of corn and alfalfa (Medicago sativa), a perennial legume. This system was developed agronomically to utilize the strips of alfalfa has barriers to overland flow of water and soil. We have also found that the alfalfa increases density of macroarthropod predators - carabid beetles, spiders and so forth - which invade the strips of corn (Stinner et al. unpubl. data). The data sets collected to date, suggest that alternating the corn with alfalfa, overall increases soil predatory activity compared to monoculture corn. In another system, we have planted corn and soybeans in alternating strips, each consisting of four crop rows spaced 0.75 m apart. Preliminary results indicate that chalcid parasitic wasps are more abundant in these strip cropped systems compared to either corn or soybean grown in monoculture (Tonhasca unpubl. data).

## SHELTERBELTS AND AGROFORESTRY: SOME CONCLUSIONS AND QUESTIONS

Agroforestry, incorporating trees into crop systems, is practiced as a dominant form of agriculture in many areas of the world, located mostly in the tropical regions (Bishop 1983, Farrell 1987). Indeed, agroforestry is a very old, traditional form of farming that has provided stable food production for thousands of years in some cases. We perceive shelterbelts and agroforestry as variations on a theme of landscape heterogeneity, where in a sense, agroforestry is a compression or intensification of shelterbelt elements into agroecosystems. Figure 2 illustrates a generalized agroforestry system, in this instance, annual crops such as maize are grown between rows of trees or shrubs. The presence of trees in an agricultural system increases the protective function of the system which must be balanced against productivity concerns. The trees not only contribute to reduced wind and water erosion, but also, as pointed out previously for shelterbelts, can absorb and retain nutrients from lower soil strata (Vergara 1982). In agroforestry systems utilizing leguminous trees or shrubs such as is practiced with Leucaena in alley cropping systems, the legume foliage is periodically cut and utilized for fertilizing nitrogen demanding crops such as maize or sorghum (Sorghum bicolor). Typically, with shelterbelts or agroforestry systems, crop yields are suppressed in an area immediately adjacent to trees. However, compensatory crop growth then occurs at some distance from the trees as a result of ameliorated microclimatic conditions (Kort 1988).

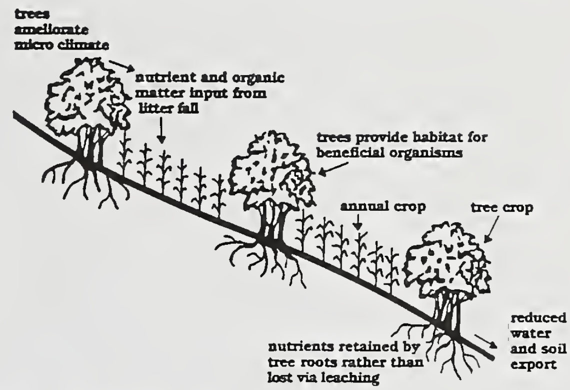


Fig. 2. Generalized agroforestry system indicating alternating structure between trees and an annual crop (from Vergara 1982).

By planting economically important tree species with annual or perennial herbaceous crops, greater potential for economic flexibility is introduced into cropping systems as well as more buffering capacity against economic losses during environmentally stressed years. The ratio of trees to herbaceous crops could be varied to meet optimal productive - protective balance for a particular landscape. That is, if land is appreciably sloped, then the ratio of trees to other crops would have to be increased to reduce soil erosion potential. Although there has to the authors' knowledge few studies directed toward invertebrate ecology in agroforestry systems, we hypothesize that due to the extreme structural complexity of these systems, pest populations are stable compared to monoculture systems.

As a concluding statement, we suggest that the current situation of grain overproduction and the increasing concern over soil conservation and water quality, offers an opportunity to increase shelterbelts, windbreaks and other forms of perennial vegetation which contribute to structural heterogeneity into agriculture lands. Such a strategy presents an alternative to placing large tracts of land out of production, in that land which is considered marginal for annual cropping systems might be utilized for sustained production if perennial vegetation were incorporated. Finally, we ask is there a viable role for agroforestry to play in temperate region countries such as the United States and Europe?

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# Tree Insect Pests in Windbreaks: Distribution and Importance[1]

J. Ackland Jones[2]

Abstract.--The relative importance of insect pests of windbreaks, as perceived by Nebraska farmers and ranchers, is presented. They generally conclude insects are not important. This conclusion is largely inferred from the absence of workable population monitoring techniques and the absence of treatment guidelines.

In addressing a subject as broad as the distribution and importance of tree insect pests in windbreaks, I come before you today more as an occasional observer than as an expert researcher. Moreover, my observations of windbreaks have been limited entirely to the northern Great Plains, and further limited largely to one state, Nebraska. Therefore, when I display a decidedly regional bias, you may attribute it to my ignorance and limited horizons. I, on the other hand, can only "call'em as I see'em!" And I will also try to call'em as a Nebraska farmer or rancher sees'em for that individual is the functional windbreak manager. It is that person's perception of windbreak pests, so often ignored when we scientists talk among ourselves, that will ultimately judge the very research of which we so fondly speak.

The phrase "distribution of tree insect pests" brings two types of studies to mind. One type consists of those studies which are concerned with delineating the geographic distribution of these pests, that is, defining their range. The other type of distribution studies are those concerned with insect distribution within a windbreak.

The geographic distribution is reasonably well known for at least the more common pests. There exists, for example, an extensive literature defining the range of various tip moths, the cankerworms, the lilac/ash borers, locust borer, carpenterworm and so on. This literature is often rather scattered and frequently not easily accessed, but it does exist.

The within-windbreak distribution of these same insects is not so well documented. Let me say at the outset, that very little of what we know, or think we know, about insect pests of windbreaks was actually learned in a windbreak. It seems that most of our knowledge of windbreak pests, from their distribution to their control, is based on studies conducted either in forests or in plantations. Relatively few studies have been conducted in windbreaks themselves. This may or may not be serious. It largely depends upon the particular situation involved and it certainly depends upon the particular question being asked. But I am made very uneasy by the sparseness of hard data defining the windbreak environment. An insect population in 100 trees planted on a 10-tree by 10-tree grid, may behave entirely differently than if that population occupied 100 trees planted in a single row windbreak. This would seem obvious, yet precious little work has been done to distinguish between the plantation environment and the windbreak environment or between insect populations in plantations or forests and those in windbreaks.

But the distribution of pests is not really what I want to focus on today. I would rather address some of the concerns of the windbreak manager about the <u>importance</u> of insect pests in windbreaks. To do that, we need to first consider the farmer's perception of the importance of the windbreak itself.

I state the obvious when I say that the Nebraska farmer believes windbreaks are "important." The Dust Bowl days woke him up and he has paid pretty good attention since. The farmer knows many benefits of windbreaks are well documented. He knows they reduce erosion of valuable top soil and he knows full well their capacity to hold snow on cropland, thereby increasing soil moisture (Scholten 1981; Read 1964). And he knows their role in providing shelter for his livestock, for wildlife and protection for his farmstead (Bond & Laster 1974;

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Read 1964). He even knows of methods to estimate the economic value of his windbreaks (Bratkovich 1977; Frank, Gavit & Heintz 1982).

To a somewhat surprising degree, I think, the Nebraska farmer is also aware of some of the studies that indicate windbreaks may benefit crops. For example, I have had farmers practically quote chapter and verse of a Nebraska study which showed that in a hot, dry year, irrigated sugar beets protected by windbreaks had a 14% greater yield than did unprotected beets (Brown & Rosenberg 1972). They know sheltering beans and tomatoes dramatically increases yields (Bagley 1964). Likewise, many of our farmers are aware of studies that showed a two bushel per acre yield increase in windbreak-protected corn and 20-26% increase in yield from sheltered soybeans (Ogbuehi & Brandle 1981, 1982).

This is not to say our farmers accept research results uncritically. One farmer told me he couldn't get very excited over that two bushel corn yield increase simply because the research was done on 40-acre fields. Actually, what he said was, "Heck, my family hasn't had a dinky little 40-acre field since Granddad first homesteaded the place." He has a point!

I would be remiss if I did not mention a few of the farmer's concerns about some negative aspects of windbreaks. Numerous workers have documented adverse effects of windbreaks on the yields of adjacent crops. These yield losses have been ascribed to such various factors as shading of the crop, increased soil temperatures, and competition for nutrients and water (Stoeckeler 1962, 1963; Read 1964; Lyles et al. 1984). The latter, competition for water, is often highly visible in the Great Plains and is a recurring source of much concern to the farmer.

Windbreaks may also serve as havens for crop pests. Our farmers are not as aware, generally, of this type of study. I doubt, for instance, that many are aware of the boll weevil's overwintering in windbreaks (Bottrell et al. 1972). Even fewer would know about, or even care about, the fall migration of plum curculio from apple orchards to windbreaks (LeFleur, Hill & Vincent 1987). They do, however, know and care that alfalfa weevils leave fields in summer to estivate in ground litter in windbreaks and fence rows (Manglitz 1958; Manglitz et al. 1978).

Having thus far simply made the point that our farmers consider windbreaks important and generally beneficial, I return to the question, "What is the importance of insects to the windbreaks?" Indeed, sometimes I wonder!

In 1986 an international symposium on windbreaks was held in Lincoln, Nebraska. Scientists from all over the world attended. Even allowing for my small-town naivete, it was an impressive turnout. In the proceedings of that symposium (Hintz, Brandle & Sturrock 1988), there are 34 invited papers. <u>One</u> deals with insects. There are also 79 submitted papers. Again, <u>one</u> deals with insects. Imagine! A four day event, dedicated entirely to windbreaks, and less than 2% of the total presentations deal with insects. Now ladies and gentlemen, I ask you, can insects be so very important? To paraphrase what a Nebraska farmer said to me after he had looked at the program for that symposium, "Are these insects important to me and my windbreak, or are they only important to graduate students' dissertations and professors' promotion and tenure?" Think about it.

I am repeatedly disturbed by our common failure to transpose research results into usable management guidelines and I know the farmer is both disturbed and confused. Just consider the situation facing the Nebraska windbreak manager. Among the Lepidoptera alone, tip moths, lilac/ash borers, pitch nodule makers and <u>Dioryctria</u> borers commonly infest our windbreaks. We have varying amounts of information on these insects. The basic biology of tip moths and lilac/ash borers is well known compared to that of the nodule maker and the <u>Dioryctria</u> borers, for example.

For some of these pests, we have various sampling techniques with which we attempt to estimate population densities, damage levels, and in-tree distributions (Gargiullo & Berisford 1981; Dix & Jennings 1982; Stephen & Wallis 1978; Van Deusen & Dix 1980). And we have insecticides registered for use against these insects. What we do not have is any sort of guidelines for the actual management of these pests in windbreaks. We make "spray and pray, kill'em and count'em" recommendations, yet these insecticide recommendations are <u>not</u> accompanied by adequate information on which the farmer-windbreak manager can make "treat or no-treat" decisions. Never have I found a paper that addresses the windbreak manager's two major questions. One: "How many bugs does it take to hurt my windbreak?" And two: "How many bugs justifies the expense of treatment?" Time and time again, our publications tell <u>how</u> to treat -- which time of year to treat, which part of the tree to treat, which insecticide to use. But do we ever indicate the population density that should be treated? I suspect not.

Farmers today, more often than not, have come to expect pest control recommendations to be coached in modern pest management terms. They have had the principles of modern pest management thrown at them time and time again, and they are constantly being told how much better off they will be if they would only put these principles into practice. As a result, they expect us to provide, at the least, action thresholds. And why shouldn't they? They have been given such thresholds for many row crops, forages and fruits. "Thresholds" are no longer foreign concepts; they are now part of the daily struggle with insect pests of crops.

But for that farmer's windbreak pests, we give him next to nothing. We just tell him where to find the insect and what to treat it with. We never tell him how to decide <u>if</u> he should treat. The farmer concludes that windbreak pest control measures are not worthwhile. His reasoning is something like this: "If control is worthwhile, those pointy-headed entomologists would have told me how to make a decision. They have not told me how to decide; therefore, the insects are probably not important."

It is quite possible the farmer is right and control measures are not worthwhile. More precisely, control measures for anything less than catastrophic infestations are not worthwhile. But how can he recognize a catastrophic infestation? And most importantly, how can he recognize it <u>before</u> it becomes a catastrophe?

Well, we entomologists have not helped him much. Our <u>practical</u> prediction abilities border on the non-existent. We simply have no sampling procedures a farmer can afford to employ. They are all too labor-intensive or too technically difficult. If the farmer cannot sample the population, he cannot monitor its growth nor predict its impact. If he cannot do that, he has no base for management decisions. With no decision-making ability, he must either treat blindly or do nothing. Most of time, I opt for doing nothing. And in the spirit of this Christmas season, I say, "Bah, Humbug! Tree insect pests in windbreaks? They are unimportant."

I challenge you to convince the Nebraska farmer and me otherwise.

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# Sampling Windbreaks for Borers and Defoliators[1]

**Judith E. Pasek[2]**

Abstract.--Development of sampling methods to detect, assess, and study insect populations in windbreaks depends upon knowledge of insect life cycles, habits, and distributions, habitat characteristics, and sampling objectives. Techniques ranging from detection surveys to population estimates have been developed for cankerworms, pine tip moths, carpenterworms, and lilac borers.

## INTRODUCTION

Any field work concerned with the presence of insects in windbreaks will require some degree of sampling, which may range from simply collecting specimens for identification to frequent, intensive sampling to estimate population densities or construct a complex life table. This paper reviews sampling techniques that are available for insect pests of windbreak plantings and factors that should be considered when designing sampling techniques. Development of specific sampling procedures depends upon knowledge of insect life histories, environmental characteristics of the habitat, and the objectives of the survey or scientific study. Sampling objectives might be to detect the presence of an insect; study the life history, population dynamics, or natural control factors of an insect pest; make trend predictions on population densities or expected damage levels; determine the need for control factors of an insect pest; make trend predictions on population densities or expected damage levels; determine the need for control measures; determine the effectiveness of control measures; or assess amount or impact of damage. More intensive sampling will be needed to establish ecological relationships than to detect insect species and determine their distributions (Morris 1960). Cost and time factors will be most limiting for extensive surveys covering large geographical areas, particularly if more than one insect species is being considered; however, the precision needed is usually low relative to that needed in intensive ecological studies (Coulson and Witter 1984).

At least 30 species of trees and shrubs are recommended for windbreak plantings in the Great Plains, and most are susceptible to attack by more than one insect species (Read 1964). More than 200 species of insects have been identified as damaging to windbreak plantings in the northern Great Plains (Stein and Kennedy 1972); additional species occur in the central and southern regions. Dix et al. (1987) identified over 90 insect pests that occur commonly in some part of the Great Plains and collectively can be found on about 60 species of trees and shrubs. This diversity of species makes surveying for insect problems difficult. Additionally, windbreak design and structure and vegetative composition varies greatly from site to site, further compounding the problems of sampling design. Development of specific sampling techniques for insect pests of windbreaks in the Great Plains has been limited to cankerworms (Lepidoptera: Geometridae), pine tip moths (Rhyacionia spp.) (Lepidoptera: Tortricidae), carpenterworms (Prionoxystus robiniae (Peck)) (Lepidoptera: Cossidae), and lilac borers (Podosesia syringae (Harris)) (Lepidoptera: Sesiidae) (Dix 1987).

Aerial surveys, which are used to detect outbreaks of insect pests in extensive forested areas, are suitable for use only in windbreak settings where species diversity is low (i.e., North Dakota). From the air, identifying tree species and differentiating damage caused by a particular insect species from other insect, disease, animal, or weather damage would be difficult, if not impossible, for areas where windbreak composition varies greatly from planting to planting. Also, extensive damage to the structure and continuity of a windbreak may already have occurred by the time it is

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detectable from the air. For example, it is desirable to detect infestation by borers before tree mortality is imminent, because loss of even one or two trees in a narrow belt can result in the development of wind tunnels (Read 1964). Ground surveys, which are useful for early detection and assessment of insect infestations (Pettinger 1979), unfortunately are infrequent, time-consuming, and costly (Dix 1976). Ground sampling also can provide detailed biological and ecological information concerning a particular insect species and is necessary for most field research endeavors. Although aerial surveys are used to detect cankerworm infestations in the northern Great Plains, available literature on sampling techniques for insect pests of windbreaks describe a variety of methods for sampling from the ground.

## SURVEYS TO DETECT INSECTS OR THEIR DAMAGE

### General Surveys

Detection surveys may be initiated in response to landowners concern about the condition of their windbreak plantings, or by the needs of specialists and windbreak managers for information on the identity and abundance of insect pests in an area. Broad categories of damage can be recognized by persons with limited training (Anderson et al. 1980); however, identification of particular insect species generally requires additional training. Defoliators are easier to detect than other types of insect pests, because most feed in exposed locations on the host plant and damage is evident at the time of feeding or shortly thereafter (Pettinger 1979). Sampling methods include counting the numbers of insects per windbreak segment, tallying catches in pheromone or light traps, classifying the intensity of damage (e.g., light, medium, heavy), or determining the number of infested windbreaks in a county (Dix 1976). Adult flight periods of lilac borers and other Lepidoptera can be monitored using attractants; this information can then be used to time insecticide applications (Dix et al. 1978, Dix and Harrell 1989). All these techniques are useful for identifying pest problems, but they do not provide much information on the importance or severity of the infestations.

Extensive, region-wide surveys of windbreaks for insect pests have been conducted for eastern North and South Dakota and extreme western Minnesota (Wilson 1962), North Dakota (Kennedy and Wilson 1969), and Wyoming (Knight et al. 1985). Windbreaks can be selected for sampling at fairly regular intervals (e.g., 5 to 20 miles) along predetermined routes selected to systematically cover the area included in the survey (Wilson 1962). Roadside sampling can be a valid procedure in forested situations (Harris et al. 1972); however, care should be taken to adequately cover the range of spatial, vegetative, and site characteristics. To gather additional information concerning insect distributions within a region being surveyed, selected windbreaks can be grouped according to similarities in characteristics of the sites or vegetation. Climatic zones based upon rainfall and temperature characteristics and upon tree age classes have been used (Kennedy and Wilson 1969, Knight et al. 1985).

Selection of trees for observation or sampling within a windbreak is usually systematic, because randomization would greatly increase the time spent at each location. To ensure an unbiased sample, however, care must be taken to sample along rather than across an environmental gradient. When more than one tree species is of interest in a given windbreak, each species needs to be adequately represented in the sampling design. All trees along selected survey lines can be sampled, or trees can be selected at regular intervals (e.g., every tenth tree) along a row after random selection of a starting point within the first group of trees equal to the sampling interval (Wilson 1962, Tunnock and Tagestad 1973).

### Assessing Insect Abundance and Damage Levels

Leaves, twigs, and trunk are scrutinized for insects, feeding damage, or insect remains (e.g., frass, webbing, cast skins) (Pettinger 1979). Windbreaks may need to be examined at time intervals, because simultaneous detection of different insect species may not be possible because life cycles differ. However, repetitive sampling will further limit the number of windbreaks and the size of the area that can be surveyed (Knight et al. 1985). The relative importance of the insects detected can often be estimated more quickly by rating the amount of damage (e.g., percent defoliation, percent of shoots affected, proportion of trees affected) than by counting numbers of insects. A useful classification of infestation levels might be as follows (Wilson 1962):

| | |
|---|---|
| No infestation | 0% |
| Trace of infestation | 1-5% |
| Light infestation | 6-25% |
| Moderate infestation | 26-60% |
| Heavy infestation | 61-90% |
| Severe infestation | 91-100% |

Such estimates can be obtained by visual observation of the tree crown or portions of the crown, by rating branch samples to the nearest 10% or 25%, or by determining the percentage of branch samples that were damaged (Carolin and McComb 1979).

Kennedy and Wilson (1969) constructed a prevalence index that can be used to compare the relative effects of insect damage between sites. Individual sample trees within a windbreak are given a numerical rating reflecting four degrees of damage (Table 1). The rating reflects the greater importance of

Table 1.--Damage categories for calculating a prevalence index.

| Host symptom | Numerical rating for individual host tree |
|---|---|
| Trees unaffected, or insects and damage scarce and difficult to detect | 0 |
| Insect or damage present but less than 5% defoliation; leaves affected, or twig tips affected | 1 |
| Noticeable damage but less than 1/4 of the tree crown affected | 2 |
| More than 1/4 of the crown affected, or any evidence of a primary boring insect in the trunk or large branches | 4 |

borer damage than defoliation to windbreak function. For each damage category, the numerical value is multiplied by the percentage of sample trees within a windbreak that fall into that category. The resulting numbers are summed for all of the damage categories to derive the prevalence index value for a given windbreak. Prevalence indices can then be averaged by climatic zone, age class, or other grouping for purposes of comparison.

## Pest-Specific Surveys

Area-wide surveys for a particular pest species can be designed more efficiently than a general survey of many insects by limiting selection of windbreaks to those containing host tree species and those that are likely to have the greatest hazard status based upon host age or site characteristics. Although sampling methods may be similar to those used in general surveys, examination or collection can be restricted to those plant parts (leaf, bud, trunk) where the insect is most abundant. Sampling can be timed to coincide with the life stage being sampled or full development of damage symptoms. Ground surveys of many insects, particularly defoliators, are directed at the larval stage; however, detection of eggs or pupae may be more suitable for some species. Selection of a life stage for sampling should be based upon its relative ease of detection and collection (Carolin and McComb 1979).

### Surveying for Wood Borers

Wood borers are considered to be the most destructive group of insect pests affecting windbreaks and they are the most difficult to detect and sample (Dix and Leatherman 1988). Ground surveys for wood borers, particularly carpenterworms and lilac borers, have been conducted in green ash (*Fraxinus pennsylvanica* Marsh) windbreaks in North Dakota to detect differences in infestation levels between land resource areas and tree age classes (McKnight and Tunnock 1973, Tunnock and Tagestad 1973, Flavell et al. 1978). A useful tree age classification for surveying borers is 0-6 yr, 7-15 yr, 16-30 yr, and 31 yr and older (Tunnock and Tagestad 1973); however, results will reflect differences in windbreak structure, vegetative diversity, and microenvironment, as well as age because older plantings tend to be wider (multiple row) and contain more tree species compared with younger plantings. Dix and Kovner (1978) present a detailed description of state-wide survey methods for detecting carpenterworm and lilac borer infestations. Sample sites should be stratified such that nine windbreaks are randomly selected in each age class within each geographic area, for a total of 36 windbreaks per area. Assuming an overall infestation rate less than 10%, a systematic sampling interval of every tenth tree should provide a confidence interval within 35-50% of the mean ($P = 0.95$). Greater precision can be gained by sampling additional windbreaks. Tunnock and Tagestad (1973) determined sample size and sampling interval based upon an assumed mean infestation level of 20% and an allowable error of $\pm$ 10% for windbreaks of varying lengths.

Surveys should be conducted in late summer or fall, when damage is most visible. A two-person crew should carefully examine the trunk and lower branches of each sample tree for damage, including holes 3-25 mm in diameter, masses of frass on the tree or on the ground near the base of the tree, and swollen bands or ridges on stems (Dix and Kovner 1978). Infestations can be easily missed. Although it is not always possible to differentiate the borer species by the damage, larvae can be readily separated (Peterson 1964, McKnight and Tunnock 1973). Larvae can be exposed by carefully removing a small portion of bark and wood using a knife or hatchet (Dix and Kovner 1978). Old and new galleries usually can be differentiated by the presence or absence, respectively, of callus (Dix and Kovner 1978); however, the number of active galleries can be underestimated by mistaking some attacks for old galleries (Tunnock et al. 1974). Damage estimates can be expressed in terms of the percentage of trees damaged or the percentage of windbreaks infested. While infestation by lilac borer of 3.5% of a state's trees may be tolerable, the same amount of damage expressed as presence in 51% of all windbreak plantings may be cause for concern (McKnight and Tunnock 1973).

Region-wide surveys can identify areas and sites with high infestation levels (>10% of the

trees infested) or high risk of infestation based upon site or age characteristics. These areas can be targeted for control efforts or for frequent monitoring to detect population trends. For example, a 1972 survey indicated that 29% of sample trees in southwestern North Dakota were attacked by borers, while damage was negligible throughout the rest of the state (Tunnock and Tagestad 1973). Thus, more intensive detection efforts and concentrated control efforts should have been initiated in the southwestern area. Surveys in 1972 and 1976 showed that carpenterworms predominated in older windbreaks, whereas lilac borers predominated in younger windbreaks (McKnight and Tunnock 1973, Tunnock and Tagestad 1973, Flavell et al. 1978). Green ash plantings less than 10 years old can be severely damaged by lilac borers and should be inspected annually to assure early detection and control implementation (McKnight and Tunnock 1973).

Although ground surveys for wood borers are time-consuming and costly, examining sample trees for damage is the most reliable survey method available, short of felling and sectioning trees (Dix and Kovner 1978). The cryptic habits of wood borer larvae and the limited availability of infested trees that can be felled with landowner permission, makes development of more intensive sampling techniques for detailed population studies difficult.

## SAMPLING DEFOLIATOR POPULATIONS AND DAMAGE

### Evaluating Control Treatments

Survey techniques, such as damage rating systems, can be used to assess the effectiveness of control treatments. To compare insecticide treatments, Hard (1979) visually rated cankerworm defoliation in single-row Siberian elm windbreaks using a five-point index. A separate rating was given for each vertical crown half on each side of 10 sample trees spaced at 30-m (100-ft) intervals (Hard et al. 1979). Ratings were averaged for each plot, and the mean defoliation indices were converted to numerical ranks for statistical analysis.

Directly sampling the pest species often has advantages over qualitative damage ratings for assessing control effectiveness. Differences in treatment effects can be detected using counts of live cankerworm larvae from four branch tips (0.5 m) collected from 10 sample trees per plot (Hard et al. 1979). Using pole pruners, a branch is collected at eye level and at midcrown level on each side of each sample tree. Stein (1969) designed a modification to a conventional pole pruner that will hold the cut branch, thereby reducing loss of insects, until it can be lowered to the ground. This equipment design has the added advantage of being easier to handle under windy conditions compared with aerial ladders or pole pruners with improvised collection baskets. Use of pole pruners also permits access to trees, especially those in interior rows, that may be inaccessible by ladder or hydraulic lift.

Both pretreatment and posttreatment sampling estimates need to be taken in order to account in the analysis for differences in starting populations between plots. Damage ratings should be conducted after larval feeding is completed, but before damaged leaves drop from the trees. For pests with one generation per year, pretreatment damage will need to be rated in the year prior to insecticide application. When the insect is sampled directly, pretreatment counts can be obtained within a few days prior to insecticide application regardless of the insect's life cycle. Also, mortality can be determined for several posttreatment time intervals. Carolin and McComb (1979) recommend doubling the number of posttreatment samples relative to the number of pretreatment samples to reduce sampling error resulting from low population densities in the treatment plots.

### Population Trends

Defoliator populations can fluctuate widely because of exposure to many different biotic and abiotic natural control factors. The ability to predict these changes helps facilitate decisions concerning the need for control measures. Some life stages are more susceptible to mortality factors than others; sampling should be conducted while the population is relatively stable to reduce errors in estimating population densities and mortality (Carolin and McComb 1979). Sampling toward the end of a life stage gives a better estimate of the surviving population, although sampling early in a life stage may be necessary for practical reasons or to provide enough lead time to implement control measures. Life table data can be useful for determining when to sample for trend prediction (Knight 1967). To predict population levels for a new brood, sampling should be directed at the egg stage or an overwintering stage (Carolin and McComb 1979). An added benefit of using an overwintering stage is that considerable time is available to conduct a survey because of the slow development rate of the insect.

Information on population trends can be obtained by modifying general detection survey methods to obtain regular, usually annual, counts of numbers of insects or amount of damage for a given sampling unit. For example, defoliators can be sampled by laying a white cloth sheet of a given size beneath a tree and beating branches within reach with a pole for a given time period, perhaps 30 seconds (Harris et al. 1972). Stein and Doran (1975) developed a technique to rapidly knock down cankerworms using a pyrethrum insecticide. Within 30 minutes of spraying, 92% of cankerworm larvae fell from the tree; after 50 minutes, the remaining 3% were dislodged by jarring the

tree. The number of larvae of the species of interest that land on the sheet per tree sampled can then be averaged for each location to give a mean number of larvae per collection. If the same sites are sampled repeatedly, trends in population fluctuations can be ascertained and may be used to predict the need for control. Whole-tree sampling for defoliators using a knockdown insecticide is especially desirable when the within-crown distribution is unknown or an absolute population estimate is needed. Felling of trees, which is sometimes used in forested situations, and other types of destructive sampling are generally undesirable for windbreak settings because of the resultant adverse effects on functional and esthetic values.

### Sample Size

Because of the high labor and travel costs involved in surveying large geographic areas, there may be a tendency to restrict the number of samples to a less than adequate number. Enough samples need to be taken so that differences in counts reflect actual differences in density of the insect population rather than inherent variation resulting from the sampling method. Although this is a primary consideration for all types of sampling design, sampling errors that mask true trends in insect populations can lead to costly mistakes concerning the need for control applications. The number of samples needed will depend upon the precision desired, the distribution of the insect within the sampling universe, and cost factors, and will vary for different species and habitats. Methods for selecting sampling units and determining distribution type and optimum number of samples are generally described in many standard statistics books, and discussed more specifically for insects by a number of authors (Oakland 1953, Waters and Henson 1959, Morris 1960, Southwood 1978, Gargiullo et al. 1983). Less precision is needed for monitoring relative changes in insect populations than for determining densities for population dynamics studies; thus fewer samples are needed per location for trend prediction. An estimate of population density with a standard error of 25% of the mean will allow a doubling or halving of the population to be detected, which is sufficient for most damage assessments (Church and Strickland 1954). Harris et al. (1972) felt that estimates within 30% of the transformed mean or within 50% of the arithmetic mean were adequate for surveying population trends of two forest defoliators, because they were not concerned with detecting small changes in populations. For the tree-beating method, three trees per site was determined to be a minimum sample size because variations were large for one- and two-tree samples. A much greater number of samples per site would require increases in time and cost that would not be justified in terms of practicality and the objectives of the survey. Optimum sample size will vary with population density because of related changes in variance, and more samples may be required for low populations (Southwood 1978). Also, the type of distribution of the insect may change with density, life stage, and habitat, and will affect the needed sample size. These factors need to be considered when designing a sampling scheme to survey populations that may encompass a wide range of densities. Precision can often be improved by increasing the number of trees or sites sampled rather than the number of sample units per tree (Oakland 1953). Fowler and Witter (1982) recommend selecting a sample size larger than the calculated optimum size in order to reduce the unknown accuracy error percentage.

### Precision

When sampling for trend prediction, precision may be increased and, consequently, the number of samples required may be decreased by restricting sampling to a subdivision of the habitat where population density is greatest or by selecting samples in proportion to differences in density between the subdivisions (Southwood 1978). For example, if 2/3 of the population occurs in the lower crown and 1/3 in the upper crown, twice as many samples could be collected from the lower crown as compared with the upper crown. Subdividing samples by aspect may be especially important in windbreaks, because of differences in microclimate on the leeward and windward sides of tree rows (Rosenberg et al. 1983) and the influence of wind patterns on the distribution of insects inhabiting and adjacent to windbreaks (Pasek 1988). Many insects tend to accumulate in the calmer air around windbreaks, especially to the leeward side (Lewis 1965, 1969, 1970). For a wide belt of mixed trees and shrubs, more insects accumulated on the side of greatest vegetative diversity, irrespective of wind direction (Bowden and Dean 1977).

Sampling precision also may be affected by behavioral characteristics of the insect being sampled. Defoliators may seek sheltered locations away from feeding sites during rainy weather or when foliage is wet, and sampling under these conditions can result in an underestimate of the insect population (Harris et al. 1972). Similarly, insect distribution may be affected by behavioral responses to sky condition (overcast, cloudy, clear), temperature, or time of day. Thus, it is important to sample under conditions that are reasonably constant in order to obtain meaningful comparisons for trend prediction. Knowledge of the habits of an insect species can be useful in refining a sampling procedure to reduce variability caused by sampling error.

## SAMPLING SHOOT BORERS AND THEIR DAMAGE

Shoot borers can pose a greater threat to

windbreak trees than periodic or occasional defoliation, because of a loss of height growth resulting from damage, deformation, or mortality of growing tips. Tree height is a major determinant of the amount and extent of wind reduction leeward of a windbreak (Read 1964). Infestations of shoot borers are less readily detected by landowners than are defoliators because feeding stages are concealed, and noticeable damage symptoms require time to develop. However, damage survey and assessment techniques are similar for the two groups of insects. Sample trees and subdivisions, such as crown level or aspect, can be selected in the same manner as described for defoliators. Shoots or branches can be examined on the tree or after removal (with hand pruners or pole pruners) for evidence of characteristic injury by shoot borers. When accessible, whole-tree sampling of small trees can be accomplished by examining all shoots using a ladder or hydraulic lift.

## Assessing Damage Levels

Infestations of a pine nodule moth, Retinia (Petrova) metallica (Busck), can be detected by the presence of pitch blisters. Sampling time is best in the fall or spring when pitch blisters are large. Examination of all branches on sample trees in a South Dakota ponderosa pine plantation indicated that total number of infested shoots increased with tree height and was significantly less for trees with sparse crowns than those with normal or bushy crowns (Van Deusen and Dix 1980). This whole-tree sampling method may be suitable for comparisons of damage among trees of similar height and age or for estimates of absolute population in a given land area. However, differences in counts may reflect changes in the available food supply or living space rather than insect population density changes (Morris 1960). To satisfactorily predict population trends or estimate changes in population density over time, counts of insect numbers or damage should be related to the number of available shoots or a constant area.

Evaluations of pine tip moth (Rhyacionia spp.) damage in the Great Plains have included counts of attacked terminals (Averill 1974) and whole-tree counts of damaged and uninfested shoots for trees up to 4 m (12 ft) (Yarger and Minnemeyer 1975). Such counts can be converted to percentage of trees infested per group, such as location or geographic seed source, or percentage of shoots infested per tree; this will reduce the bias resulting from counts of attacks on trees of different sizes. Although restricting sampling to terminals saves a lot of time, Berisford and Kulman (1969) found the level of damage caused by the Nantucket pine tip moth, R. frustrana (Comstock), to the top shoots (terminal and first whorl) to be poorly correlated with total damage within the tree. Sampling top shoots is useless for estimating damage for very high or very low population densities, because sample shoots may be completely infested or not at all infested, respectively. Conversely, the increased accuracy of whole-tree sampling is very time-consuming, especially if trees are large.

Dix and Jennings (1982) studied the within-crown distribution of R. bushnelli Busck on 8-yr-old ponderosa pines, and determined that sampling all tips on whorls 3 through 6, 4 through 6, or 4 through 7 (numbering from the top beginning with zero for the terminal) gave accurate estimates of damage for trees up to 3 m high. The percentage of damaged tips varied significantly with whorl number and tree height; however, the general infestation pattern was similar for whorls 2 through 6 regardless of tree height. Agreement between whorl sampling and whole-tree condition can be checked by taking whole-tree samples for 10% of the sample trees. This sampling scheme is not applicable to trees taller than 3 m because upper buds are less susceptible to attack than are smaller trees; however, damage by pine tip moths is primarily a problem for young trees.

## Population Density Estimates

Estimates of shoot damage are adequate for certain purposes, such as damage assessment; however, such counts do not provide adequate estimates of absolute population or population density. Damaged shoots may not contain any individuals of the pest as a result of mortality, migration to another shoot, or emergence of the adult. Using x-ray techniques, Stephen and Wallis (1978) described a linear correlation between number of apparently infested shoots of loblolly pine (Pinus taeda L.) and number of shoots that actually contained larvae or pupae of R. frustrana. This relationship might be used to better estimate population levels from damage estimates. Additional relationships would need to be established for different host tree species, site conditions, and community structures. But even this correction may be unsuitable in many cases, because damaged shoots also may contain more than one individual of the pest species. As many as 17 immatures of R. frustrana and 30 immatures of R. bushnelli may inhabit a single shoot (Swenk 1927, Warren 1963), although the number of occupants per shoot typically averages between one and two (Lashomb 1975, Swenk 1927). Thus, shoots must be dissected to obtain accurate population counts for population dynamics studies, hazard ratings, and assessment of control efforts.

## Life Table Sampling

Examination of damaged shoots only is unsuitable for population estimates of life stages that cause little or no damage (e.g.,

eggs) or for determination of survival rates. Gargiullo et al. (1983) devised an intensive sampling technique for life table studies of R. frustrana. Sample trees were subdivided by crown level and all sample units within a stratum were numbered. Several small shoots were pooled to form a single sampling unit, so that all sampling units contained approximately equal amounts of foliage. Numbers were drawn to randomly select sample shoots, regardless of condition. Shoots were removed, surfaces were thoroughly examined, and damaged shoots were dissected to obtain counts for all life stages present. Two or three shoots per stratum should be sampled until optimum sample size can be determined from population parameters. Insect counts can be converted to estimates of mean number of immatures per tree, per shoot, or per hectare.

Feeding intensity for a given site and time can be indicated using mean number of insects per shoot of a given size. To compare population levels between different plantings or through time in a single planting, sample values need to reflect differences in available resources. When tree densities are similar between plantings, mean number of immatures per tree can be used. This value can be calculated by multiplying the mean number of shoots per tree for a large sample by the mean number of insects per shoot in a subsample (i.e., double sampling) (Gargiullo et al. 1983). When tree densities differ, population levels should be expressed on a per area basis (i.e., absolute population). Estimates of absolute population are nearly always required for long-term population and life table studies because they provide a stable unit for frequent sampling and a common reference point for stages that inhabit different parts of the habitat. Also, they permit comparisons between the insect population and populations of vertebrate predators (Morris 1960).

## SEQUENTIAL SAMPLING

Considerable time can be saved in evaluating populations by using sequential sampling methods rather than a fixed number of samples from a fixed number of trees per site. Sequential sampling classifies populations into broad categories, such as light, medium, or heavy, or needing control versus not needing control. Each sample is examined in sequence until the cumulative number of insects for the number of samples taken falls into one of the population classes (fig. 1). Fewer samples per site will be needed for populations that are very low or very high (Waters 1955), although a sufficient number of sites still must be sampled to be representative of the target area or population. Population trends for a region can be determined by comparing the number of plots that fall into each class during successive years (Carolin and McComb 1979). Development of sequential sampling methods requires

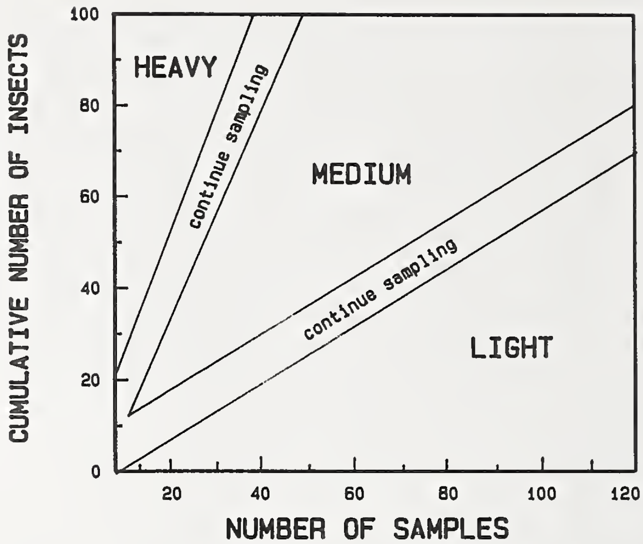


Figure 1.--Generalized sequential sampling decision chart.

considerable knowledge of the insect, its mathematical distribution on the sampling unit, and its relationship to damage for setting reasonable class limits (Waters 1955, Knight 1967, Fowler and Lynch 1987). Consequently, sequential sampling techniques have been developed for only a few forest insect pests.

Sequential sampling plans using egg mass counts have been developed for the forest tent caterpillar, Malacosoma disstria Hubner, in forested areas (Connola et al. 1957, Shepherd and Brown 1971), and may be adaptable to windbreak settings. Sampling ten branch tips [76-cm (30-in) long] per tree was more accurate and practical than visually counting all egg masses on standing or felled trees. This sequential sampling method reduced sampling time by 87% compared with examining a fixed number of samples, while retaining similar error rates (Connola et al. 1957). Shepherd and Brown (1971) improved sampling efficiency by determining that optimum sample size was two branches per tree selected from the uppermost four branches exclusive of the terminal. Accuracy also was improved by taking historical information on stage of an outbreak into account when determining defoliation class. Before these methods are applied to an environment vastly different than what they were designed for, a study needs to be conducted to verify whether the distribution of egg masses and the relationship between egg mass density and amount of defoliation holds for windbreak settings.

## ECONOMIC DECISION-MAKING

Often, the objective of sampling an insect pest population is to aid in the decision-making process concerning the need for control. Ideally, such a decision is based upon the

economic injury level, which is the lowest pest population density that will cause economic damage (Pedigo et al. 1986). Economic injury levels are dependent upon the market value of the commodity in question and the relationship of insect injury to a defined unit of the commodity. Unfortunately, windbreak values are difficult to quantify, and windbreaks cannot readily be subdivided into economic units. Several methods have been devised to place a value on a windbreak based upon the cost of establishment and maintenance, adjacent cropland yields, or ratings of windbreak characteristics (Bratkovich 1977, Frank et al. 1982); however, such values have not been related to insect damage and population densities.

Until a better understanding of the relationships between insect population levels, insect injury, and windbreak functions and values can be attained, pest specialists and windbreak managers must rely on their experience and intuitive guesses to assess the severity of pest infestations based upon damage or population estimates. Even insect species that occur at seemingly innocuous levels can seriously affect the value of tree plantings when the cumulative effects of such insects are combined with damage from other insects, diseases, or environmental stresses, such as drought and chemical contaminants (Waters 1986). Also, the significance of an insect pest population will vary with the structure of a planting. For example, two or three dead trees may cause little concern in an older, multiple-row windbreak, but would seriously affect the function of a one-row windbreak. Insect pest problems are likely to become more serious as a greater proportion of windbreaks are represented by narrow, single-species plantings, not only because there will be fewer trees in the plantings, but because of the development of monocultures that are conducive to insect population buildups.

## CONCLUSIONS

Development of sampling techniques for insects affecting windbreak plantings has lagged behind studies of insect biology and control. This has resulted, in part, because information on the life-cycle and distribution of a particular insect species is needed to devise an efficient sampling method with acceptable degrees of precision and accuracy. Also, the number of researchers working on sampling methods for windbreak insects is limited. No "universal" sampling method can or will exist because of the great diversity of insect species and windbreak habitats (Graham and Stark 1954).

Simple, inexpensive sampling techniques to detect, evaluate, and monitor insect populations and trends are needed to acquire information upon which to base pest management decisions for windbreak plantings. However, their development generally requires intensive sampling to delineate population distributions, relationships between population density and damage, and influences of biotic and abiotic factors. Host age and vigor, parasite and predator populations, and climatic conditions, are in a constant state of flux and further complicate efforts to obtain uniform information concerning the insect population (Bongberg 1958). Different methods need to be developed to meet different sampling objectives, even when considering a single insect species. General surveys, pest-specific surveys, damage assessments, population trend prediction, sequential sampling, and evaluation of control effectiveness are most frequently used by persons concerned with making pest management recommendations and decisions; population density estimates, life table sampling, treatment comparisons, and intensive sampling to identify distribution patterns are more frequently required to answer specific research questions. Area-wide detection surveys generally will require less intensive sampling and lower precision than complex methods designed to establish ecological relationships.

Sampling techniques for insect pests of windbreaks in the Great Plains have been described for cankerworms, pine tip moths, carpenterworms, and lilac borers. These techniques range from detection and damage assessment surveys to estimates of population density. More complex methods for life table studies and sequential sampling schemes have not yet been documented for windbreak plantings. Research is needed to develop additional methods for sampling insects in windbreaks and to determine the effects of insect populations and damage levels on windbreak function and value.

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# Role of Host Susceptibility and Site Influences on Damage Caused by *Dioryctria* spp. Pine Borers[1]

Mark O. Harrell[2]

Abstract.--Dioryctria spp. borers are the most damaging insect pests of pine windbreaks in Nebraska. The insects girdle trees or branches or weaken them so they can be broken easily by wind or snow. Ponderosa pine is the species in Nebraska most susceptible to infestation and damage. Austrian pine and Scotch pine are intermediate in susceptibility, and jack pine is least susceptible. Phloem thickness, degree of water stress, and water holding capacity of the site appear to influence infestation levels.

## INTRODUCTION

Zimmerman pine moths and related Dioryctria spp. borers are the most damaging insect pests of pine windbreaks in Nebraska. These insects tunnel just beneath the bark of the trunk and large branches. The tunneling can girdle the trunk or branches or weaken them physically so they can be broken easily by high wind or snow. Heavily infested trees can be killed.

Three species of Dioryctria spp. borers are present in Nebraska. The Zimmerman pine moth, Dioryctria zimmermani Grote, is present in the Omaha area along Nebraska's eastern edge; D. ponderosae Dyar is present in the Nebraska National Forest and vicinity in central Nebraska; and D. tumicolella Mutuura et al. has been found throughout most of the central and western portion of the state (Harrell 1984). The information presented in this paper discusses the infestation and damage caused by the Dioryctria spp. borer populations in central and western Nebraska.

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## INFESTATION AND DAMAGE SAMPLING PROCEDURES

As Dioryctria spp. borers feed beneath the bark, soft, reddish pitch masses form on the bark surface. These pitch masses are pine resin mixed with a smaller amount of borer feces. The pitch masses appear at the openings to the tunnels in which the insects are feeding and are usually on the trunk just beneath a branch. When the insects stop feeding, the pitch mass becomes dry, brittle and light yellow. Current infestation levels can be determined by counting the number of "new" soft, reddish pitch masses. Infestations of the previous two to three years can be estimated by counting the number of "old" pitch masses that are dry and yellow. Large infestations or infestations that have continued over several years can cause branches or tops of trees to die or break. Heavily infested trees can have substantial structural damage or be destroyed completely.

To indicate the level of damage caused by Dioryctria spp. borers in each tree, a rating scale of 0 to 2 was used. A value of 0 was given to trees with no visible structural damage. A value of 1 was given if one or two branches were dead or broken as a result of Dioryctria spp. borer infestation, and a 2 was given if more than two branches or the top of the tree were dead or broken.

## SUSCEPTIBILITY OF INDIVIDUAL TREES

Differences among pine species in their susceptibility to Dioryctria spp. borers were determined by examining 45 trees of each of four pine species in the Nebraska National Forest as described above for infestations and damage. The four pine species were Austrian pine (Pinus nigra

Arnold), jack pine (P. banksiana Lamb.), Scotch pine (P. sylvestris L.), and ponderosa pine (P. ponderosa Laws.). In addition, the degree of water stress, thickness of phloem at four feet, and growth rates of diameter and height were measured in 15 trees from each species located within a one-hectare (2.5-acre) area. Water stress was estimated by measuring the needle water potential of three clusters of needles on the south side of the tree at solar noon with a pressure chamber (Waring & Cleary 1967). An average phloem thickness was determined by cutting two sections of bark and phloem from the tree with a cork borer, measuring the phloem thickness, and averaging the two measurements. Diameter growth rates for the previous two years and the previous 5-year average were determined in a similar manner by using an increment borer to remove cores from the trunk on opposite sides of each tree. Height growth rates were determined by measuring the the leader growth for each of the two previous years and the previous five-year period.

Of the four pine species examined, ponderosa pine had the greatest number of pitch masses per tree and the greatest amount of damage caused by Dioryctria spp. borers (Harrell 1986a). Scotch pine had an intermediate number of pitch masses per tree, and Scotch pine and Austrian pine had intermediate degrees of damage. Jack pine and Austrian pine had the lowest number of pitch masses per tree, and jack pine had the lowest damage rating of all the species.

When the data for the four pine species were analyzed together, a significant negative correlation appeared between the current Dioryctria spp. borer infestation level and needle water potential. Trees with high infestation levels tended to have relatively high levels of water stress. This correlation was not present when the data were examined separately for each pine species, possibly because the sample was too small. The correlation suggests a possible relationship between the level of Dioryctria spp. borer infestation and the degree of stress in the tree. The number of pitch masses and phloem thickness were correlated also, with ponderosa pine having the thickest phloem. This may be another characteristic that contributes to the higher susceptibility of ponderosa pine to Dioryctria spp. borers.

## SUSCEPTIBILITY OF WINDBREAKS

Site characteristics important in determining Dioryctria spp. borer infestation and damage levels within a windbreak were determined by examining 102 windbreaks within and immediately surrounding the infested region of central and western Nebraska. Fifty windbreaks contained ponderosa pine, 26 contained Austrian pine, 22 contained Scotch pine, and four contained jack pine. These numbers reflect the proportions of windbreaks planted with these species within the state. At each site, 15 trees were examined, five randomly selected from each third of the windbreak. The site characteristics examined at each windbreak were tree species, age, and size; soil texture, nutrient levels (N, P, and K), pH, excess lime, organic matter, water holding capacity, degree of compaction, degree of vegetative competition from groundcover (type and density) and other trees (basal area), annual and seasonal precipitation, temperature extremes, and exposure to sun and wind. Dioryctria spp. borer infestation and damage levels were determined in the same manner as described earlier.

While no significant differences were found in infestation and damage levels among the four pine species examined at the 102 sites, the simple ranking of most infested species (number of pitch masses per tree examined) to least infested was the same as had been found in the study within the Nebraska National Forest. Ponderosa pine was highest, Scotch pine and Austrian pine were intermediate, and jack pine was the lowest. This simple ranking supports the results discussed earlier concerning the relative susceptibilities of the four pine species.

Of the 40 ponderosa pine windbreaks examined within the region known to be infested with Dioryctria spp. borers, more that half had evidence of current or past borer infestations, suggesting that the insects can readily disperse to new locations and infest new windbreaks. Of the infested ponderosa pine windbreaks, those located on sites with a low ability to retain water in the soil generally had higher infestation levels than did similar windbreaks on sites with a greater ability to retain water. The sites that drain water more quickly may be more stressful for the trees than the sites that retain water longer, and the added stress may predispose the trees to greater infestation. Other explanations are possible, and more investigation is needed in this area.

## WINDBREAK MANAGEMENT RECOMMENDATIONS

Dioryctria spp. borers are serious pests of pine windbreaks in Nebraska and adjoining states. To reduce the chance of serious damage caused by these pests, a more resistant species, such as jack pine, should be selected during the windbreak planning process. Since windbreaks are usually planted where needed and with little regard to soil characteristics of the area, windbreak managers should at least be aware of the increased potential for damage from Dioryctria spp. borers if the soils have a relatively low ability to hold water, such as sandy soils.

When an infestation of Dioryctria spp. borers begins to cause branch mortality, control measures should be taken to reduce the effects of the insects on the windbreak. Insecticides are available that can be used to keep infestation and damage levels low (Harrell 1986b, 1986c). If an insecticide is used, label instructions should be read and followed carefully.

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# Opportunities for Using Attractants to Manage Borers in Windbreak Trees[1]

Mary Ellen Dix[2] and Mark O. Harrell[3]

Abstract.--Borers are the most destructive insects in windbreaks. They weaken their host, decrease plant growth, and provide entry portals for other insects and disease organisms. Damaged trees either die or take several years to recover. Management of borers is difficult because life histories frequently are not well understood and larvae usually are concealed within the tree. Attractants can be used to study the life cycle and behavior of borers. This paper discusses the use of attractants to detect, monitor, predict, and reduce populations of borers in windbreaks. Success of a technique is dependent on the insect species, pest behavior, and site conditions.

## INTRODUCTION

During the past 20 to 30 years attractants have been identified for many borers, and techniques have been developed for using these attractants to capture borers in traps (figure 1). Researchers have used attractants to learn more about the biology and behavior of pest species and to develop techniques for managing outbreaks.

Attractants for many species of tree pests can be used to: (1) detect infestations and differentiate between pest species (Daterman and McComb 1970, Stevens et al. 1980, Dix et al. 1987); (2) monitor adult flight (Dix et al. 1978, Gentry et al. 1978, Riedl 1980, Dix and Doolittle 1985, Dix and Jacobson 1986); (3) estimate current populations or damage levels, and predict future population size or damage levels (Sower et al. 1984); and (4) reduce population size or damage levels (Overhulser et al. 1980, Sower et al. 1982, Sartwell et al. 1983). These techniques were developed for use in forests, orchards, and plantations. They may be used alone or in combination with other pest management approaches.

The number of management techniques available varies with the species, and depends on the research effort, and the behavior and biology of the species. This paper discusses the common uses and potential applications of attractants in windbreaks. Specific examples will be limited to pine shoot borers, Dioryctria spp. pine borers, and hardwood stem borers.

Figure 1.--Larvae of carpenterworms (Prionoxystus robiniae (Lepidoptera:Cossidae)) mine the trunk and branches of ash, elms, willows, and other hardwoods. Branches or entire trees may be killed or structurally weakened.

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## WINDBREAK CHARACTERISTICS

Each windbreak is a unique ecosytem, with its own combination of size, shape, tree species, density, understory vegetation, and neighboring land use. Windbreaks differ from natural forests because trees within a windbreak normally are all the same age and are planted in rows. Windbreaks have fewer and often longer rows than are found in orchards and plantations.

Most windbreaks established within the last 20 years are only one to five rows wide and contain one to five tree species. Fifty meters to more than 100 kilometers may separate neighboring windbreaks. The uniqueness of each windbreak makes it difficult to establish general guidelines for the use of attractants.

Wind velocities are usually higher and more constant in windbreaks than in natural forests, orchards, or plantations. This constant exposure to wind affects the performance of attractants and opportunities for their use. For example, wind blowing at right angles to a long, narrow windbreak will blow the attractant away from the trees, so attractant lures need to be spaced at closer intervals than in a forest. Lure performance also can be affected by the constancy of the wind. Cotton wick lures quickly lose their attractiveness when placed in windbreaks on the Great Plains (Dix et al. 1987a).

## DETECTING, IDENTIFYING, AND MONITORING OUTBREAKS

Attractants provide a very effective and quick means for detecting sparse populations of potentially damaging borers, and can provide an early warning system for detecting population build-ups (Daterman 1980). At present, attractants are used to detect the carpenterworm (Prionoxystus robiniae (Peck) (Cossidae))(Neill 1979; Dix et al. 1979, 1987a), the lilac borer (Podosesia syringae (Harris) (Sesiidae)) (Dix et al. 1978), the Nantucket pine tip moth (Rhyacionia frustrana (Comstock) (Tortricidae)), the metallic pine pitch nodule moth (Retinia metallica (Busck) (Tortricidae)), and the boxelder twig borer (Proteoteras spp. (Tortricidae)) (Neill 1980, 1982; Dix et al. 1984; Dix and Underhill 1988) (figure 2). Extensive field trials with each species have identified the most effective trap density, placement, height, and maintenance schedule, duration of trapping, attractant release rate, and attractant formulation (Dix et al. 1978, 1979, 1987a; Dix and Underhill 1988).

Identifying the species of borer damaging a tree is frequently difficult because the larvae and their tunnels are concealed within the tree, several species may cause similar damage (Dix and Kovner 1979), and many windbreak managers are unskilled in the identification of these

Figure 2.--Platform-cylinder traps can be used to monitor the flight of male carpenterworms. Traps are lined with a sticky adhesive and baited with dispensers releasing (Z,E)-3,5-tetradecadienyl acetate.

insects. Because of their specificity, attractants can be used to help with borer identifications. For example, three species of Proteoteras that mine boxelder (Acer negundo L.) twigs have similar morphology, life cycles, ranges, and damage characteristics. Attractants of the male moths can be used to identify the species present at a site (Neill 1982).

Dioryctria ponderosae Dyar and D. tumicolella Mutuura et al. bore in the trunks of pines in central and western Nebraska (Harrell 1984). They have similar morphological characteristics, hosts, and damage, but different life cycles. Thus, assessment and control procedures differ for each species. Harrell[3] and cooperators (pers. comm.) currently are identifying the attractants for these two species. These attractants can be used to identify the species present in a windbreak so that the control measure most appropriate for the species can be selected.

Tree managers and researchers also use attractants to delineate flight periods of borers. For example, spring emergence of adult carpenterworms depends on the cumulative atmospheric temperature, and can vary between years by up to four weeks (figure 3). Traps baited with the male attractant can be used to identify the start, peak, and end of the adult flight period (Dix et al. 1982).

## EVALUATING AND PREDICTING POPULATIONS

Attractants to assess and predict populations of metallic pine pitch nodule moths, carpenterworms, and other borers are being refined for use in windbreaks. Attractants also should be ideal for determining the relative abundance of these and other borer species, especially those with small and widely

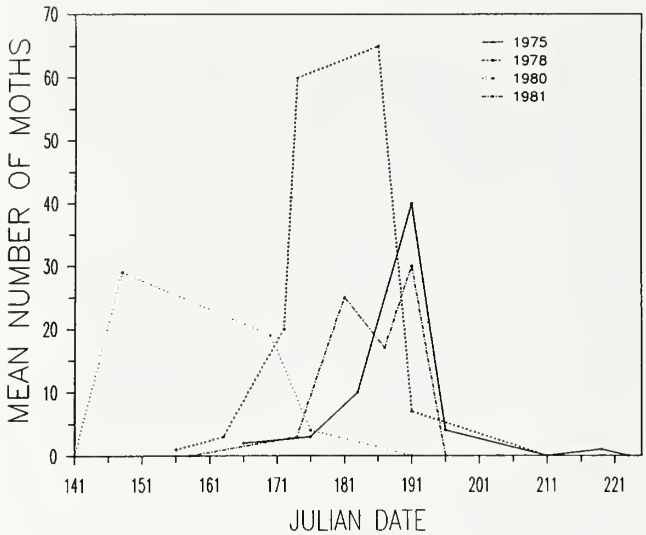


Figure 3.--Seasonal flights of male carpenterworms in Bottineau County, North Dakota.

distributed populations (Gentry et al. 1978). Attractants can be used by people unskilled in insect identification and recognition of insect damage. They can reduce the need for the time-consuming and labor-intensive destructive sampling methods. But attractants provide only a preliminary population estimate or generalized survey of a large area, and are not as precise as some destructive sampling methods (Sower et al. 1984).

Several factors need to be considered for developing evaluation techniques using attractants. Repetitive visits to sample sites may be needed to record trap catch data and maintain traps (Riedl 1980). Furthermore, assessment of relative abundance can be made only after larvae have damaged the tree and adults have emerged. The abundance of future populations may be difficult to predict because unforseen environmental conditions may affect survival of the pest or its natural enemies.

Assessment techniques must be adapted to individual windbreak because windbreaks differ greatly. Survey results are affected by a number of factors including trap location within or near the windbreak, windbreak design, and direction of prevailing winds (Dix 1989). For example, traps are more effective if evenly spaced along the entire length of a single-row windbreak. In wide multiple-row windbreaks traps are more effective if arranged in a block design.

Trap placement in relation to undergrowth is also important. Traps placed in heavy understory vegetation will catch fewer moths than those placed above the understory or at sites where the understory vegetation is sparse (Dix et al. 1979).

Male carpenterworms, lilac borers, and other borer species search large areas for females and can be drawn from long distances to an attractant. This emigration of males from outside the immediate area makes determination of their abundance difficult. Use of low attractant release rates and shortened trapping periods should minimize this long-distance attraction (Daterman 1980; Dix 1989). However, even lures with low release rates, when placed in isolated windbreaks, attract males of some species from outside windbreak. For example, low concentrations of carpenterworm and lilac borer attractants are so potent they attract moths from windbreaks more than 0.8 kilometers away (Dix, unpublished data). The possibility of catching moths that originate from downwind windbreaks increases with the length of time traps are left hanging and wind speed.

## CONTROLLING POPULATIONS

Attractants can be used in four ways to reduce the size of an infestation or damage level: (1) to time insecticide applications, (2) to prevent mating by removal of all the males from the area, (3) to disrupt mating, and (4) as an integrated approach with other control techniques.

### Timing of Insecticide Applications

Use of traps baited with attractants to time insecticide applications is an inexpensive, time-efficient, and uncomplicated procedure widely used by tree managers. A typical application of this technique is the use of a lilac borer attractant, (Z,Z)-3,13-octadecadienyl acetate, to time insecticide applications against first instar larvae. Sticky traps baited with the attractant are placed in the infested windbreaks at least one to two weeks before the expected start of male flight. Timing is critical because initiation of moth flight is dependent on spring temperatures and can vary by up to six weeks. An observer who can identify lilac borers checks traps for males at least once each week, preferably every one to three days. About 10 to 14 days after the first male moth is caught, trunks and large branches of ash (Fraxinus spp.) and lilac (Syringia spp.) should be sprayed with an insecticide registered for control of the lilac borer (Dix et al. 1978). Similar techniques can be used to reduce the population size of carpenterworms, tip moths, metallic pine pitch nodule moths, and other borers whose male attractants have been identified.

### Mass Removal of Males

Removal of borer males from a population by mass trapping is a commonly mentioned use of attractants. When successful, this procedure substantially reduces or eliminates mating. To be effective, traps need to be spaced one to three trees apart throughout the site, and

changed before they become saturated with moths. This technique has been used with mixed results on lepidopterous pests of apples, grape berry moths, red banded leaf rollers, and peach twig borers. Although injury levels to some commercial crops has been reduced damage levels may be higher than commercially acceptable. (Taschenberg et al. 1974, Trammel et al. 1974, Madsen et al. 1976, Madsen and Carty 1979, Wilson and Trammel 1980, Hathaway et al. 1985). Also, this technique was most successful for codling moth control when the site was isolated and initial populations were low (Madsen and Carthy 1979, Wilson and Trammel 1980). In 1981, this technique was used successfully in a program to completely eradicate a small, isolated gypsy moth outbreak in Lincoln, Nebraska[4] (Steve Johnson, pers. comm.).

In 1975, mass removal of male lilac borers failed to reduce damage and abundance of borers from four green ash (Fraxinus pennsylvanica Marsh.) windbreaks in southwestern North Dakota. Initial lilac borer populations may have been too large and the sites were not sufficiently isolated. More males were caught in the traps than would be expected based upon the number of emergence holes found in the trees, indicating that many lilac borers emigrated into the area from neighboring windbreaks at least 0.8 kilometers away (Dix[2] and Nielsen[5], unpublished data). Similar results would be expected for other strong fliers, such as carpenterworms.

### Mating Disruption

Mating can be disrupted and reduced by inundating an area with an attractant or a chemical that prevents mating (Payne 1981). This procedure can effectively reduce damage when a pest population is small and isolated (Taschenberg et al. 1974). It also can be used as a preventative maintenance treatment in high-risk areas, and to create a buffer zone to reduce possibility of dispersal of a pest into a high-value planting (Daterman 1980, Sower and Overhulser 1986). The effects of mating disruption on the population also may be enhanced by the increased abundance of predators (Westigard and Moffitt 1984).

Aerial and ground applications of a microencapsulated attractant has been used successfully to disrupt mating and reduce damage levels of the western pine shoot borer, Eucosma sonoma Kearfott (Lepidoptera: Tortricidae), in the northwest (Overhulser et al. 1980, Sower et al. 1981, 1982; Sartwell et al. 1983). Damage levels were significantly reduced for two or three generations after treatment (Sower and Overhulser 1986). Although mating disruption has not been attempted in windbreaks, these sites may be ideal for this technique because of isolation from other plantings and insect populations. However, mating disruption in windbreaks may be expensive because complete saturation of the area with an attractant requires a higher dosage per tree than that needed in a forest (Dix and Leatherman 1988). Placement of the attractant may be more time consuming in windbreaks because more releasers would be needed per tree.

Microcapsules, polyvinyl choride releasers, and hollow fibers have been successfully used to release attractants either aerially or from the ground (Beroza et al. 1974, Overhulser et al. 1980, Sartwell et al. 1983). Spacing of attractant releasers is important because a high level of attractant per unit of area must be maintained throughout the site during the flight period (Farkas et al. 1974). Dispenser placement by ground crews in trees taller than ten meters is impractical and time consuming (Sartwell et al. 1983). Also, numbers of attacks and damage levels may increase if more adults are attracted to the windbreak.

### Integrated Control

When pest densities are high, the most effective strategy for reducing population and damage levels is to combine insecticidal control with attractants. Insecticide applications can reduce large populations to a size that can be effectively reduced still further by mass removal of the males or mating disruption (Beroza et al. 1974). A completely integrated control and monitoring program includes the use of attractant traps to detect new populations, assess their size, identify the most appropriate time to apply an insecticide, and further reduce or maintain low population levels. As commercial attractants become available for more pest species, the use of an integrated approach will become more common.

## CONCLUSIONS

Attractants of many important insect pests of windbreak trees have been identified. Simple, inexpensive, and effective techniques have been or are being developed for detecting and monitoring pest populations, evaluating population size, and timing insecticide applications. Tree managers and researchers can use modifications of these techniques to help identify pest species. The use of attractants to assess or predict populations size and damage levels in windbreaks is difficult because of immigration of males from neighboring areas. However, attractants should be very effective in windbreaks that are well isolated from neighboring windbreaks or trees. Techniques developed for reducing damage levels by mass

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removal of males and mating disruption will likely be most effective for small, isolated populations of those insects that severely damage trees.

Attractants for most pest species are not commercially available. Additional research is needed to develop more effective and economical techniques with attractants for assessing and predicting pest populations and reducing their damage.

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# Potential Pest Problems in Windbreaks[1]

**Robert D. Averill[2]**

Abstract.--Potential insect pests in windbreaks may be declining through better plant selection for given growing conditions. The amount of potential insect host material is increasing on the Plains through the Conservation Reserve Program. Windbreaks are poorly understood as providers of insect habitat. The Gypsy Moth *Lymantria dispar* (L.) is perhaps the most serious insect pest in the future on windbreaks.

A presentation on potential pest problems in windbreaks requires the use of a crystal ball. Mine broke sometime ago when I realized that insect pests seldom read or heed what is written about them. But, with that out of the way we can proceed to contemplate the potential pest problems in windbreaks on the Great Plains based on what has happened in the past, and some trends I see in the future.

Trees have been planted on the plains since the homesteading days of the 1800s. The Timber Culture Act of 1873 offered homesteaders 160 acres of land, solely on the provision that they plant 40 acres of trees (Davis 1976). This Act was repealed in 1891. One of the country's most ambitious forestry projects took place during the Great Depression of the 1930's. Between 1930 and 1942, more than 200 million trees and shrubs were planted on 30,000 farms in windbreak strips totalling 18,600 miles in length (Hanks 1976). This all took place on the plains between Canada and the Texas Panhandle.

The program had its critics. One critic put his finger on an important research need. "Personally," he said, "I feel that the project has very little chance of success unless they are able to find highly resistant tree species. Certainly those species which have been most commonly used as windbreaks will fail." (Davis 1976). This comment was made through hindsight, but it will continue to guide the direction of research on tree species in the plains. Entomologists will play a key role, just as they have in the past.

There is no question that windbreaks are important to farmers and ranchers and on the plains within the towns and cities are accepted and nurtured with great pride. Neither trees nor windbreaks are inexpensive. It takes five to ten years after planting before they begin to provide protection, and by age sixty they need to be replaced. During that time they are subjected to several drought cycles, a variety of insect and disease pests, changing ownerships, and management objectives. We have heard earlier today about many of the currently important insect pests of windbreaks.

Stein & Kennedy (1972) published a key to shelterbelt insects listing over two-hundred insect species found on twenty-nine hosts in the northern Great Plains. Their work served as the standard for many years and is still a valuable reference for insect identification. In 1986, the Great Plains Agricultural Council brought together a group of authors under the technical coordination of Mary Ellen Dix (Dix et al. 1987) and published *Common Insect Pests of Trees in the Great Plains* which contains over one-hundred of the most commonly found insect pests on fifty-nine hosts. One might think that with the greater diversity in tree species that some sort of ecological balance is unfolding on the plains and that insect pests are reducing in numbers. However, such wishful thinking doesn't appear to be the case. What it does reflect, in my opinion, is an acceptance that some insects are less of a pest problem than previously thought. Also, we are incorporating "lessons learned" in selecting planting material and site selection to reduce pest problems. We recognize now, more than in the past, that we are planting trees in stressful situations, by selecting the least stressful site for a given tree, perhaps over the long haul our pest problems will be less. But as our depth of knowledge increases we continue to be impressed by our lack of knowledge of what we don't know or didn't expect.

An example will suffice. Juniper is a wonderful species which can withstand drought quite well. Its' popularity has increased on the Central Plains over the past fifty years as a "survivor." Its popularity with insects is increasing also. Cedar bark beetles of the genus *Phloesinus* are more commonly encountered than in the past. The same can be said for the aphid genus *Cinara*, as well as spittlebugs, *Aphrophora*. At the same time a variety of diseases are becoming more common. It is probably only a matter of time before some insect becomes a more dominant

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problem requiring greater attention. The odds improve as more juniper is planted. The importance of diversity of species in a windbreak cannot be overemphasized to minimize severe insect induced losses.

At the same time, one cannot think of a windbreak as just a wall providing protection to the adjacent farm or field. It also serves as a niche to a variety of insects which affect agricultural production. The production of alfalfa as a crop for cattle is important. The exportation of alfalfa to horse farms often brings a premium price for quality. Grasshoppers can be a problem to the alfalfa grower requiring chemical treatment. Biological control is environmentally acceptable and is encouraged. To practice biological control within an integrated pest management or resource management system requires thinking about the whole ecosystem. Blister beetle (*Epicauta* sp.) larvae feed on grasshopper eggs, and, as adults, feed on siberian pea shrub, honey locust and other shrubs and trees. In one county, a pest specialist recommended that more Siberian pea shrub be planted to encourage higher populations of blister beetles to control grasshoppers. Exported alfalfa was almost banned in Florida when several expensive race horses died of cantharadin poisoning. Growers were crimping their alfalfa to speed drying, the result was blister beetles crimped to alfalfa stalks. Obviously, the encouragement of blister beetles to prey on grasshoppers by increasing the amount of Siberian pea shrub must be accompanied by not crimping alfalfa and possibly other considerations to bring together a viable enterprise. Now and in the future, pest management considerations on the plains must take a holistic approach from both the biologic and socio-economic perspective.

The 1985 farm bill had a new provision in it which is called the Conservation Reserve Program (CRP). The objective of the CRP is to place marginal or eroding cropland into permanent vegetation, grass, trees, and shrubs. A variety of practices are encouraged. Those that incorporate woody vegetation include the establishment of forest cover, windbreaks and wildlife habitat. In our five state region of Kansas, Nebraska, South Dakota, Wyoming, and Colorado, 6.2 million acres have been placed in CRP through the first 6 signup periods. Seven percent of this land base (455,000 acres) has been placed in forest cover, windbreak and wildlife habitat plantings.[3] We can be hopeful that through the knowledge gained during the past 100 years that better choices have been made regarding the selection of plant species for given site conditions. We also need to keep in mind that the sites selected for this program have had varying degrees of erosion during their cropping history and that these sites will have a high potential to harbor a variety of insect problems during the life of these plantings. Many of the same pests that have been a problem in the past will continue to be pests in the future.

There is one new pest attempting to become established, the Gypsy Moth, *Lymantria dispar* (L.). As people move from the generally infested areas of the East to the Plains, or as people vacation in the Plains, the probability of gypsy moth infestation increases. With the wide variety of suitable host material present in the Plains there is increasing potential for a small but steadily increasing population presence of the insect, and the need for detection trapping has become apparent. PPQ/APHIS has the primary responsibility for Gypsy Moth detection and coordinates with the various State and Federal agencies in conducting their program. Trapping has been conducted since the early 1980's in our Region. While single moth catches generally do not represent an infestation, their continued occurence indicates that it is only a matter of time before isolated infestations become common. Generally each Plains state places between six and seven hundred traps each year. Each year improvements are made in trap area selection based on the highest probability of moth occurrence. Thus, areas around military bases, towns and major river drainages along the Interstate system receive the greatest attention where the greatest traffic flow occurs from East to West. A vast majority of isolated tree stands and windbreaks are not sampled; however, it is considered an acceptable risk at this time. As detection occurrence increases, detection trapping will need to be increased.

While numbers of moths captured to date are small, the results indicate a steady influx over time. For instance, in Kansas two moths were caught in 1984, one each year in 1985 and 1986 and zero the past two years.[4] In Nebraska, an isolated infestation was treated at the Lincoln Airpark West in 1983 and 1984. No moths were detected in 1985 or 1986. One was detected in 1987 and none this year.[5] In Colorado, Wyoming and South Dakota, where the Plains merge with the mountains, moths have been detected with increasing frequency in destination vacation areas such as Mt. Rushmore in South Dakota (Johnson & O'Neil 1986) and the Greater Yellowstone Area of Wyoming (Lessard, et al. 1987). Single catches have occurred in Cheyenne and Laramie. Isolated infestations occur in Fort Collins and Boulder, Colorado (O'Neil & Sharon 1988) which are being treated. No moths have been detected in these States away from their mountainous portions.

The probability of successful Gypsy Moth invasion in the Plains is real. Its establishment as a permanent resident is only a matter of time. I personally feel that this will occur within twenty years. The problem then will be of dealing with a variety of isolated, recurring, infestations on an annual basis.

Another future problem which lacks understanding is the use of pesticides in the agricultural environment. Many windbreaks are thought to be declining as a result of aerial applications of herbicides. While the majority of aerial application is done with care, it is still a challenge to minimize drift into adjacent nontarget areas. This low level of pesticide application, especially herbicides, could be a factor in predisposing woody vegetation to insect pests.

The role of windbreaks in providing a refuge for insects is poorly understood. Windbreaks, with their structural diversity provide many niches for hiding cover, food, overwintering, etc. As the use of biological control agents increases and chemical insecticides decrease, I believe we will gain an increased understanding and realize that shelterbelts have other benefits which we are only beginning to recognize.

And as a last thought, changes in climate, both short term and long term have a significant influence on the potential insect

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[3]. Ripley, William. 1988. Personal conversation. USDA Forest Service, Rocky Mountain Region, Lakewood, Colo.

[4]. Gansberger, Paul. 1988. Personal conversation. USDA Plant Protection and Quarantine, APHIS, Wichita, Kansas.

[5]. Smith, Bart. 1988. Personal Conversation. USDA Plant Protection and Quarantine, APHIS, Lincoln, Nebr.

activity in an area. When coupled with non-native vegetation growing on a variety of sites, with a variety of other plants, one cannot help but be fascinated by the potential pest problems of windbreaks and the web of predation and parasitism throughout the trophic levels of the unnatural systems we have created on the plains for the betterment of man.

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U.S. Department of Agriculture
Forest Service

# Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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